What Will it Take to Revive Nuclear Energy ?

[Assuming you want to]

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Answer

- High priced alternatives such as natural gas, “clean” coal and renewable sources.
- Continued safe operations
- Increasing power demand
- New plants that are quicker to build with capital costs low enough to meet the target bus bar electricity prices of the competition.
- Continued support from the President and Congress.
- Continued concern about global warming
- Courageous leaders in the utility business?
- A few informed Wall Street analysts ?

Present Situation

- *It doesn't get any better than this for nuclear energy!*
  - *Very Good Nuclear Regulatory Commission*
  - *Combined Construction Permit and Operating License*
  - *Early site permits supported by DOE*
  - *Concern about Global Climate Change*
  - *Rising and highly volatile natural gas and oil prices*
  - *Great rhetoric from the President and Congress about need for nuclear energy for environment, security and stability*

But ?

- Lots of good ***words*** but,

- ***No new orders !***

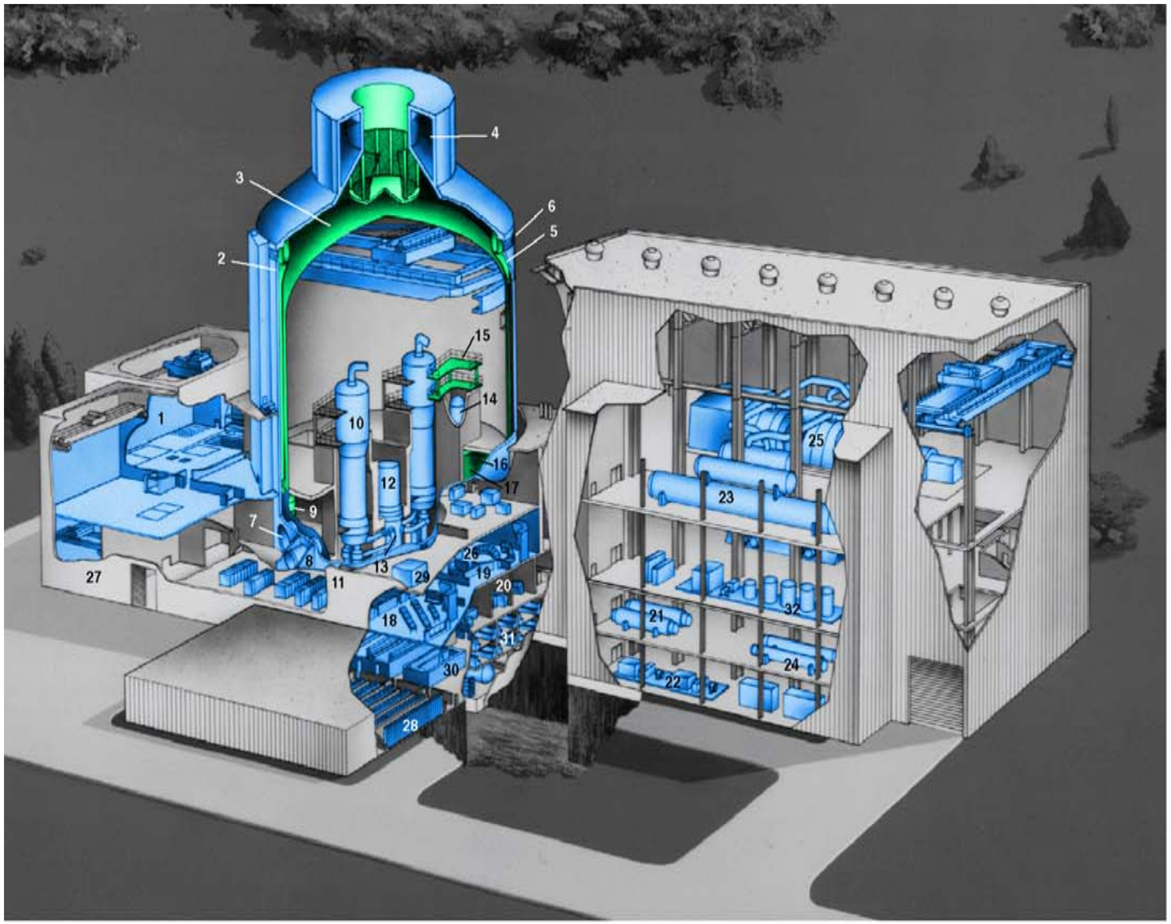
Why ?

- High Cost ?
- Psychology ?
- Wall Street Effect ?
- Bad Products ?
- Lack of Need ?
- Risk Averse ?
- Wanting to be Second ?
- Lack of “Leadership” ?
- All of the above ??

Present New Market Offerings

- AP-1000 (Westinghouse)
  - 1,000 Mwe – PWR
- ESBWR (General Electric)
  - 1390 Mwe - BWR
- EPR (Framatome – ANP)
  - 1,600 Mwe – PWR

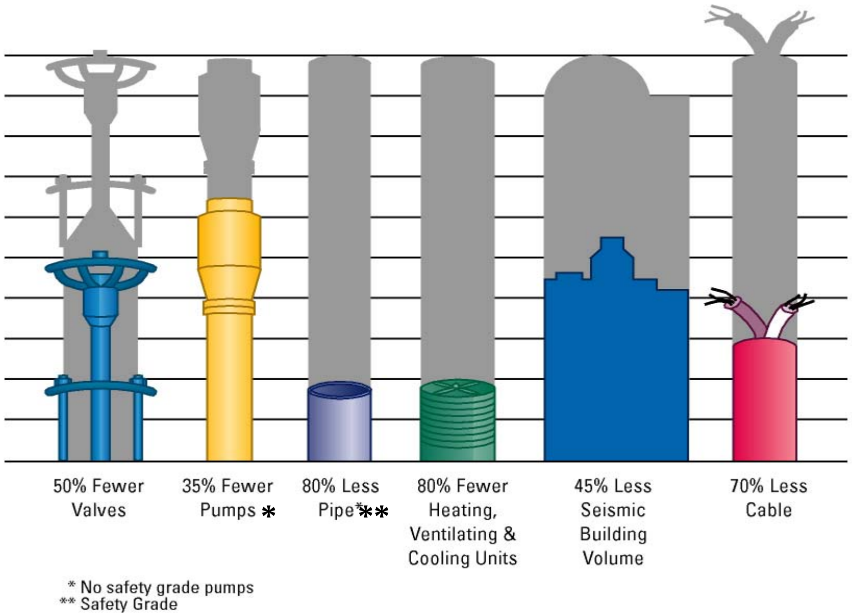
AP1000 Site Plan



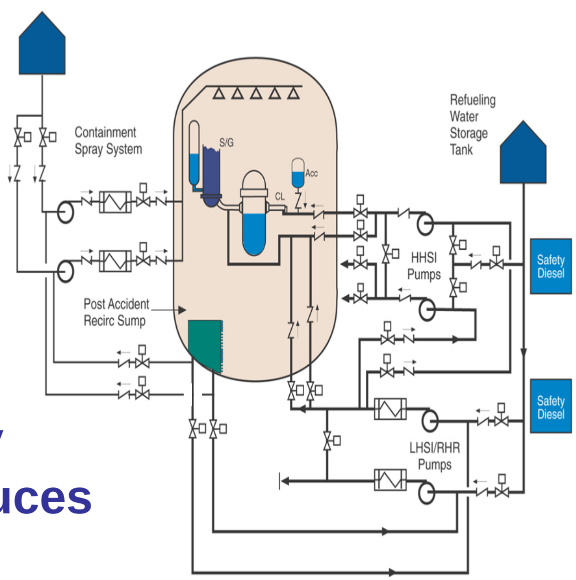
Key:
- Proven Through Use
- Proven Through Testing
- Advancing Technology

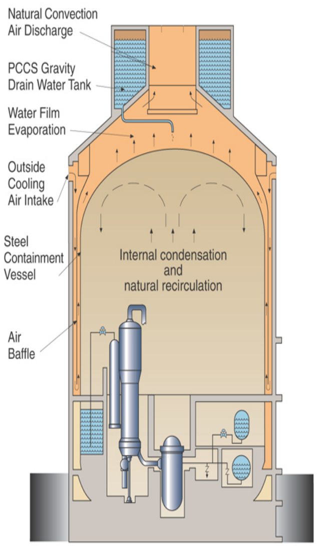
1. Fuel Handling Area
2. Concrete Shield Building
3. Steel Containment
4. Passive Containment Cooling Water Tank
5. Passive Containment Cooling Air Path
6. Passive Containment Cooling Air Inlets
7. Equipment Hatches (2)
8. Personnel Hatches (2)
9. Core Makeup Tanks (2)
10. Steam Generators (2)
11. Reactor Coolant Pumps (4)
12. Integrated Head Package
13. Reactor Vessel
14. Pressurizer
15. Depressurization Valve Module
16. Passive Residual Heat Removal Heat Exchanger
17. Refueling Water Storage Tank
18. Technical Support Center
19. Main Control Room Systems
20. Integrated Protection Cabinets
21. High Pressure Feedwater Heaters
22. Feedwater Pumps
23. Deaerator
24. Low Pressure Feedwater Heaters
25. Turbine Generator
26. Main Control Room Finalization
27. Rad Waste Area
28. Batteries (Non-1E)
29. Ventilation Equipment
30. Electrical Equipment
31. Batteries (1E)
32. Process Equipment

AP1000 - A Cost Competitive Design



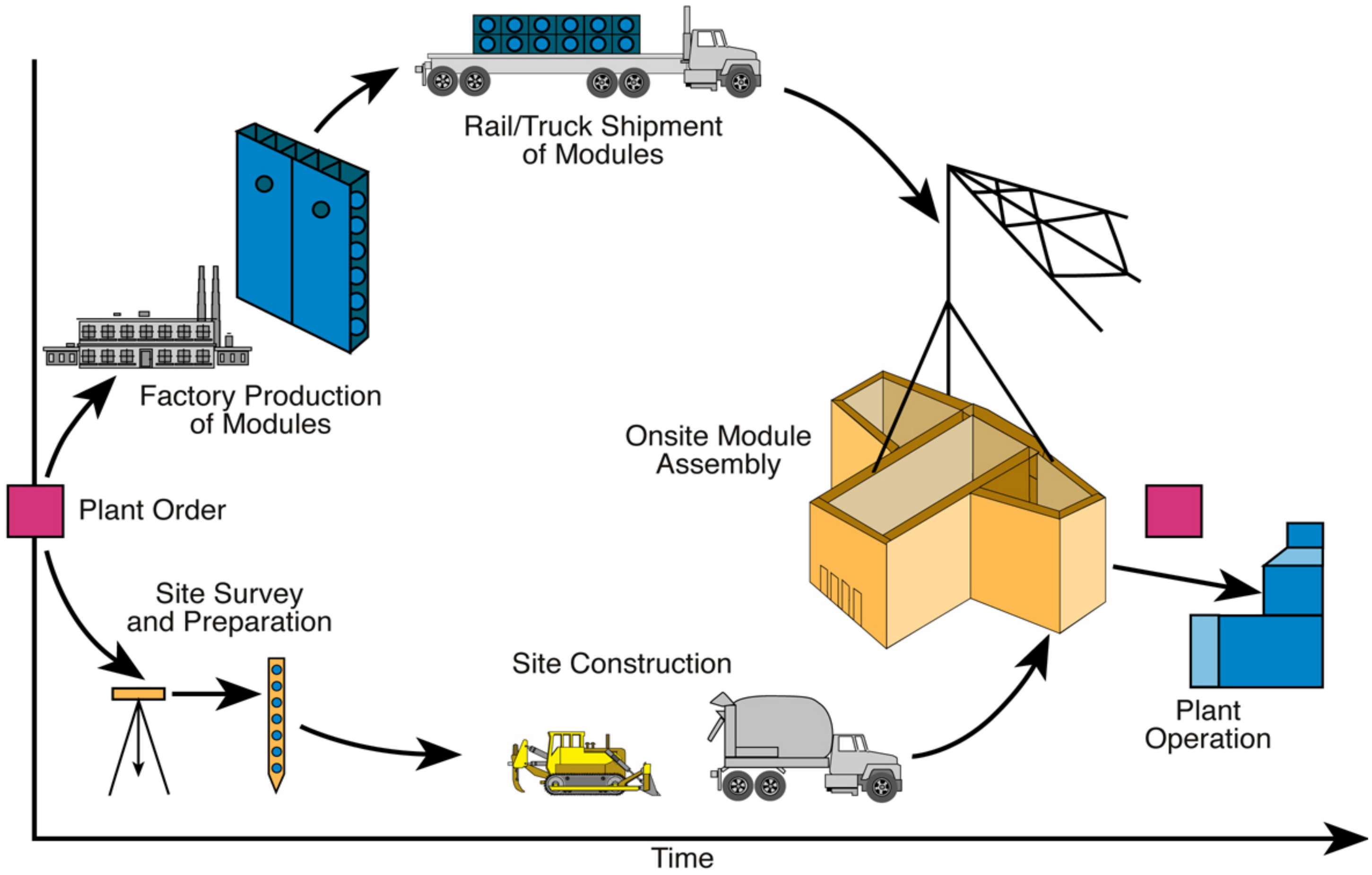
Passive Safety Systems Eliminate Components and Reduce Costs





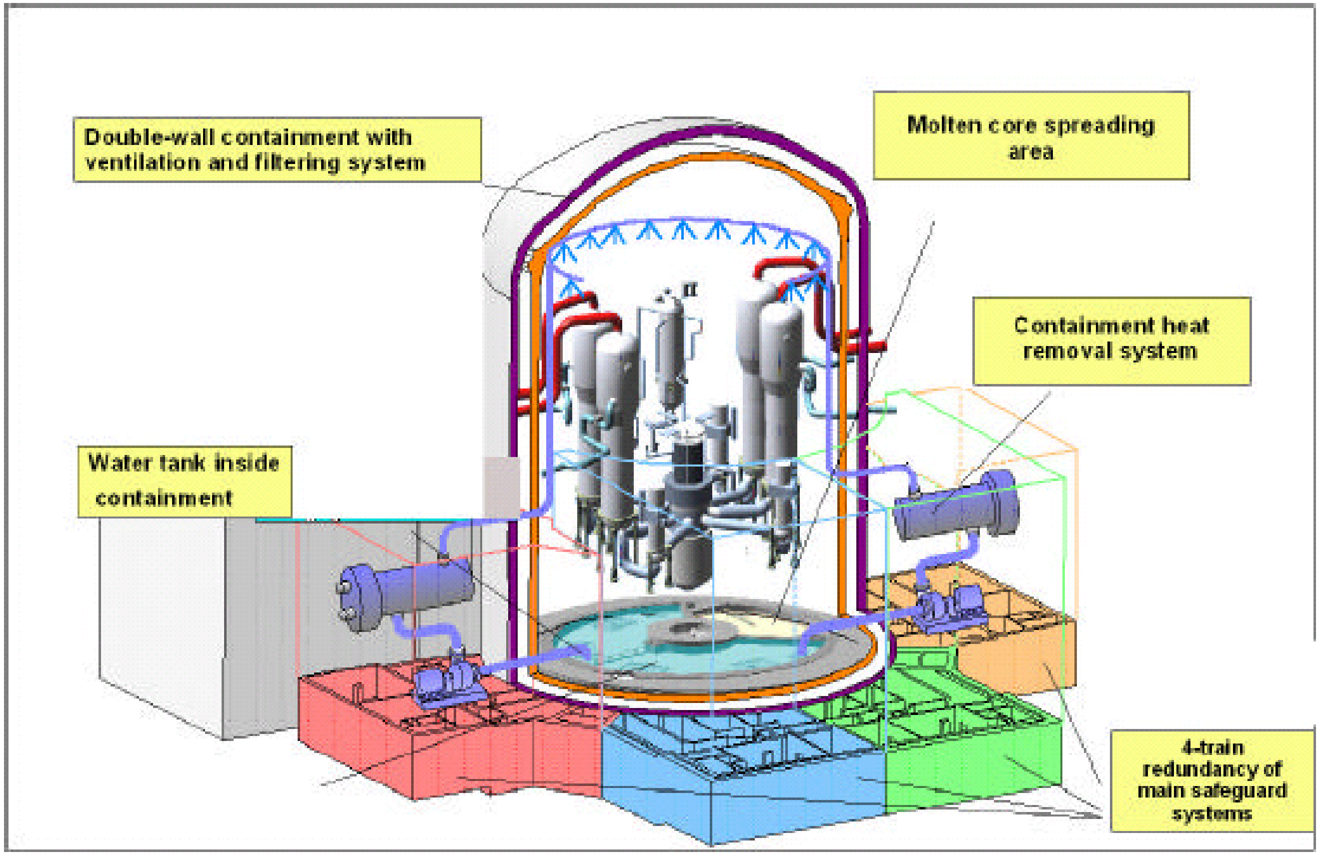
Simplification of Safety Systems Dramatically Reduces Building Volumes

Parallel Tasks Using Modularization Shorten Construction Schedule



European Pressurized Water Reactor

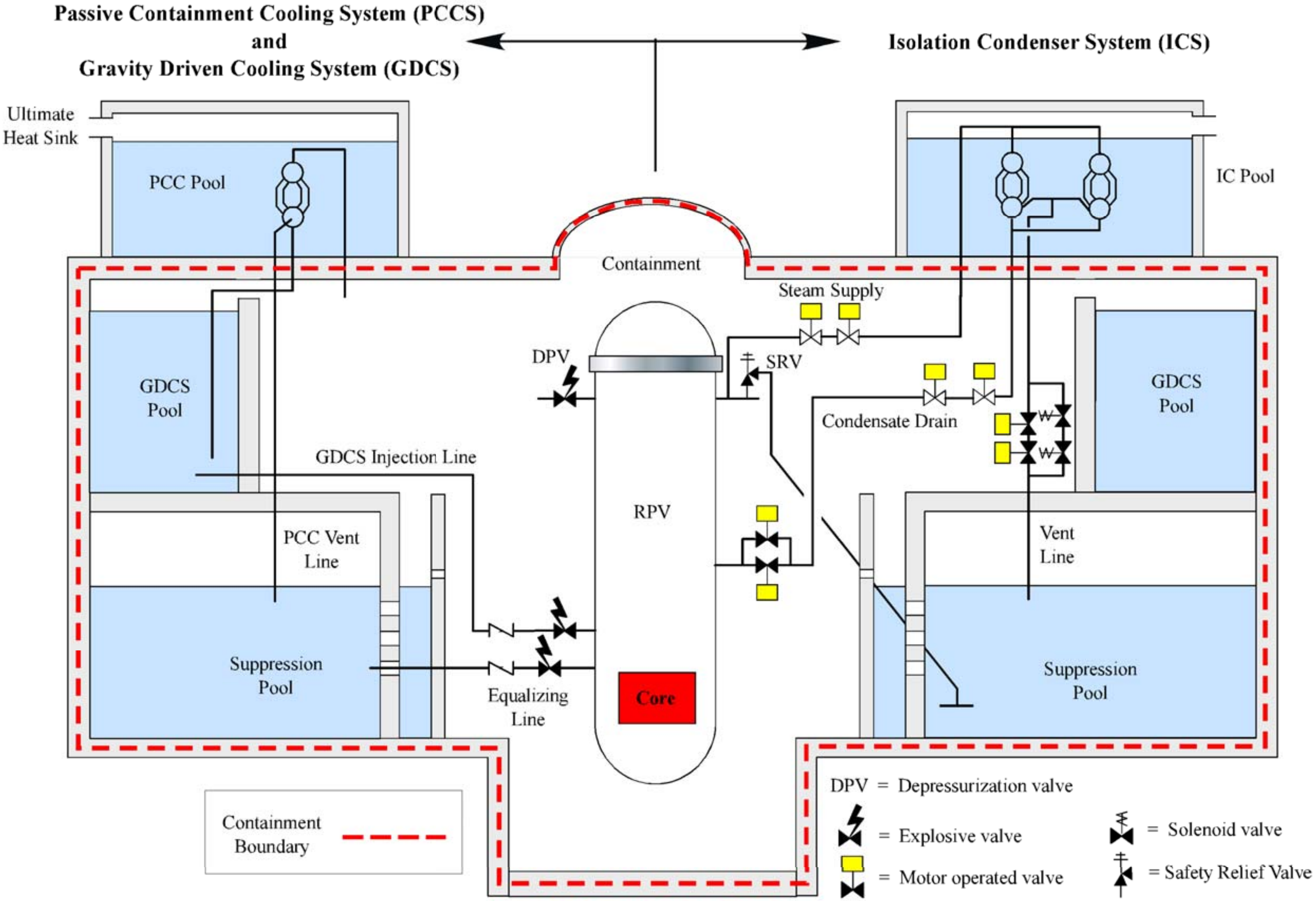
EPR Safety System



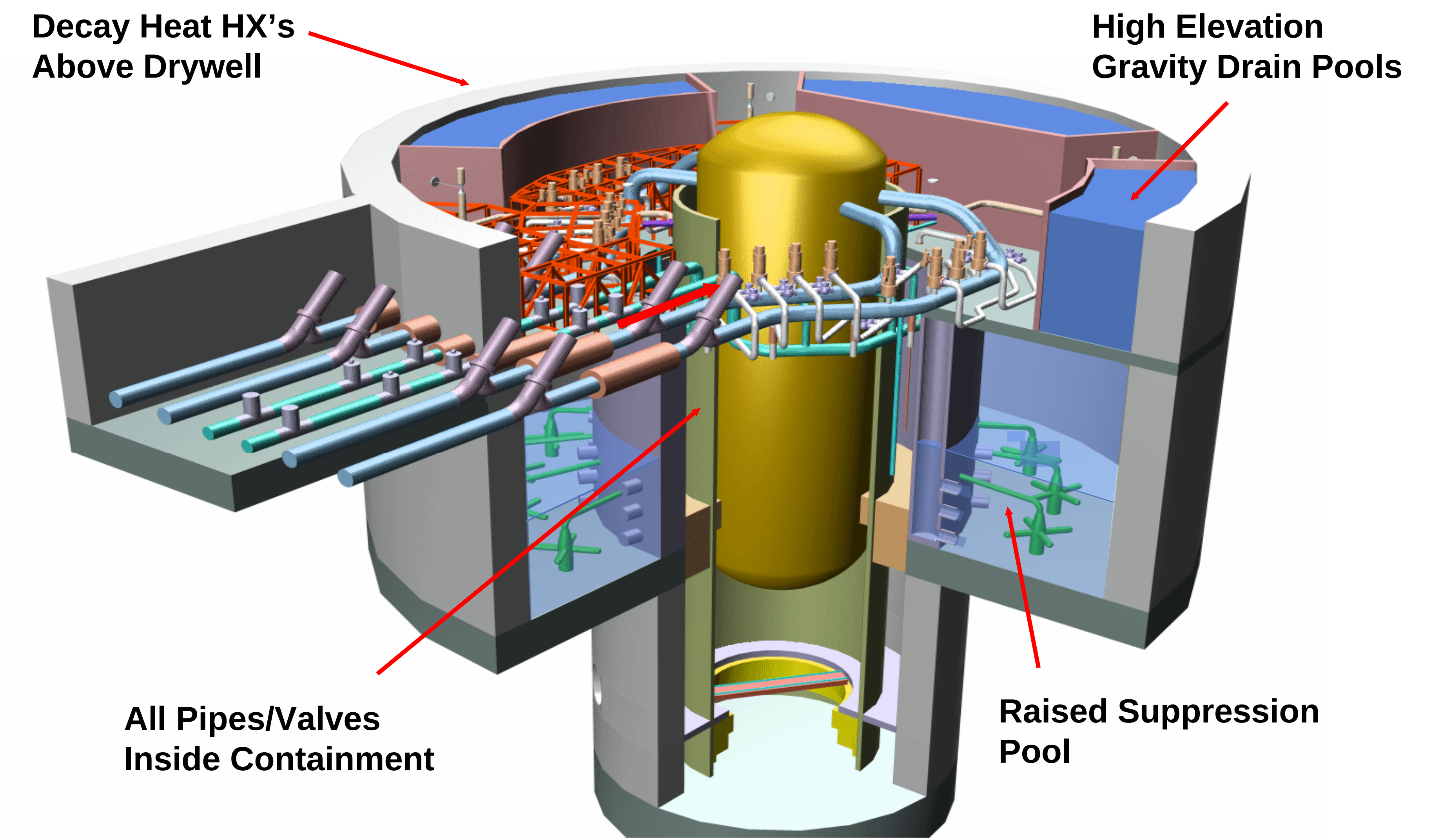
ESBWR Design Features

- Natural circulation Boiling Water Reactor
- Passive Safety Systems
- Key Improvements:
  - Simplification
    - Reduction in systems and equipment
    - Reduction in operator challenges
    - Reduction in core damage frequency
    - Reduction in cost/MWe

Passive Safety …



Economic Simplified Boiling Water Reactor (ESBWR) Passive Safety Systems Within Containment Envelope



Differences relative to ABWR

ABWR	ESBWR
Recirculation System + support systems	Eliminated (Natural Circulation)
HPCF (High Pressure Core Flooder) (2 each)	Combined all ECCS into one Gravity Driven Cooling System (4 divisions)
LPFL (Low Pressure Core Flooder) (3 each)	
RCIC (Isolation/Hi-Pressure small break makeup)	Replaced with IC heat exchangers (isolation) and CRD makeup (small break makeup)
Residual Heat Removal (3 each) (shutdown cooling & containment cooling)	Non-safety shutdown cooling, combined with cleanup system; Passive Containment Cooling
Standby Liquid Control System–2 pumps	Replaced SLCS pumps with accumulators
Reactor Building Service Water (Safety Grade) And Plant Service Water (Safety Grade)	Made non-safety grade – optimized for Outage duration
Safety Grade Diesel Generators (3 each)	Eliminated – only 2 non-safety grade diesels

2 Major Differences – Natural Circulation and Passive Safety

Certified Designs

- AP-600 (Westinghouse)
- ABWR – 1250 Mwe (General Electric)
- System 80^+ - 1300 Mwe(Westinghouse/CE)

Problem – although certified, nobody in the US is buying – cost?

Trends

- More passive safety features
- Less dependency on active safety systems
- Lower core damage frequencies – 10^{-6}
- More back up safety systems – more trains
- Some core catchers
- Larger plants to lower capital cost $/kw
- Simplification in design
- Terrorist resistant features
- Construction time reduced but still long 4 years

Some Facts

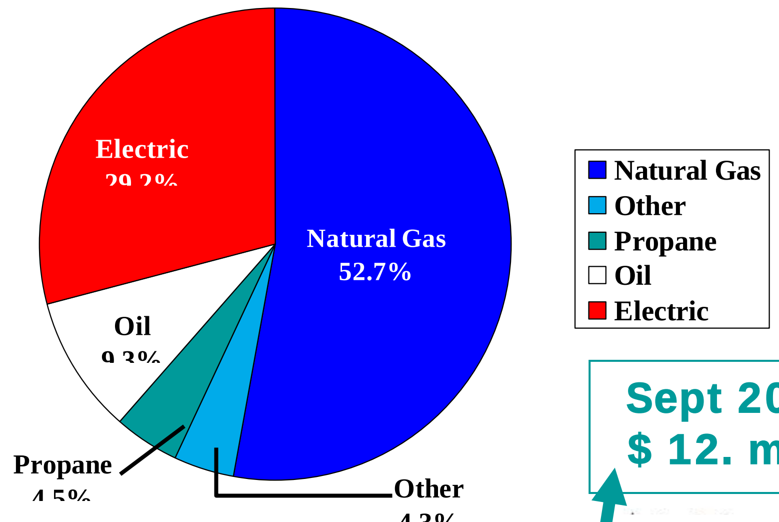
- 103 US reactors, 440 World reactors in 33 countries.
- 98.5 nuclear GWe is 13% of installed capacity but provide 20% of electrical energy.
- No order for nuclear plants since 1975, but in 2002 nuclear energy production was the highest ever.
- US plants have run at 90% capacity in 2002, up from 71% in 1990.
- 16 reactor licenses extended, from 40 years to 60 years of operation, 18 more reactors in process.
- 2.5 GWe of uprates were permitted in the last decade. 5.0 GWe are expected by industry by 2010.

- Bottom line: Utilities are making money with nuclear plants and electricity rates from these plants are stable and quite low on a production cost basis – fuel and operations and maintenance.
- This is Good for new orders!!!

Gas and Oil Prices Continue to Rise

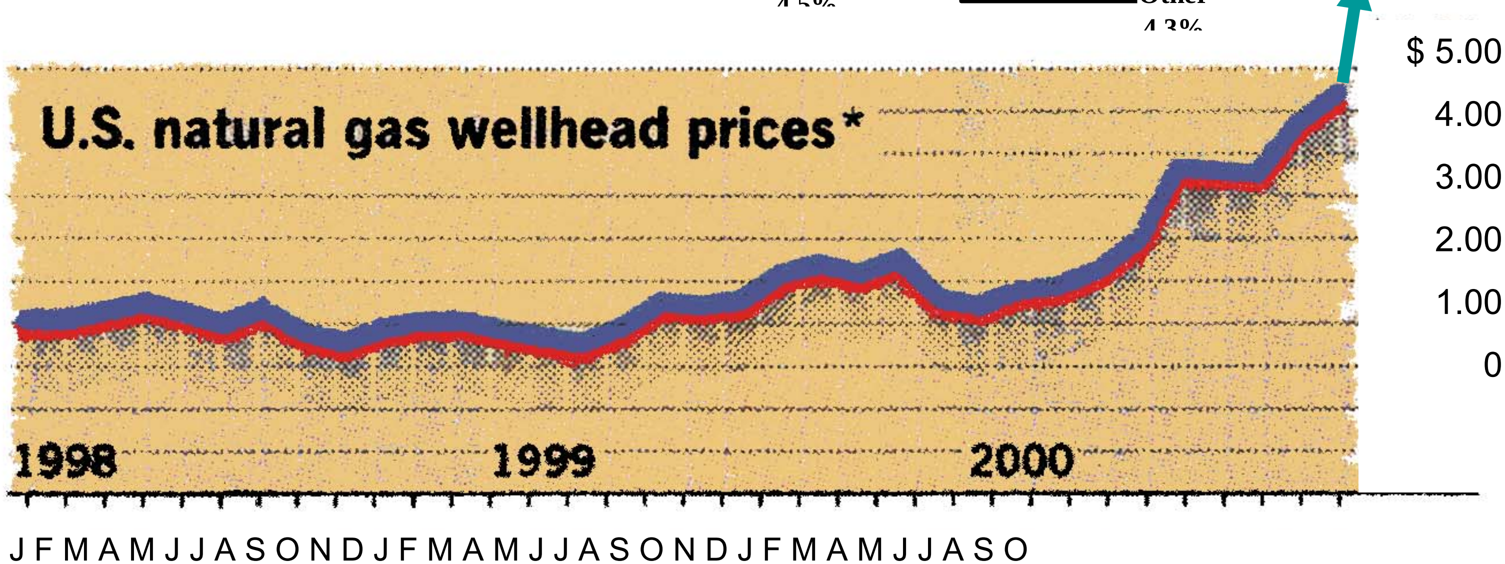
U.S. home heating sources

***1997 estimate**



Source:
Energy Information Administration

Sept 2005 Price
$ 12. mcf



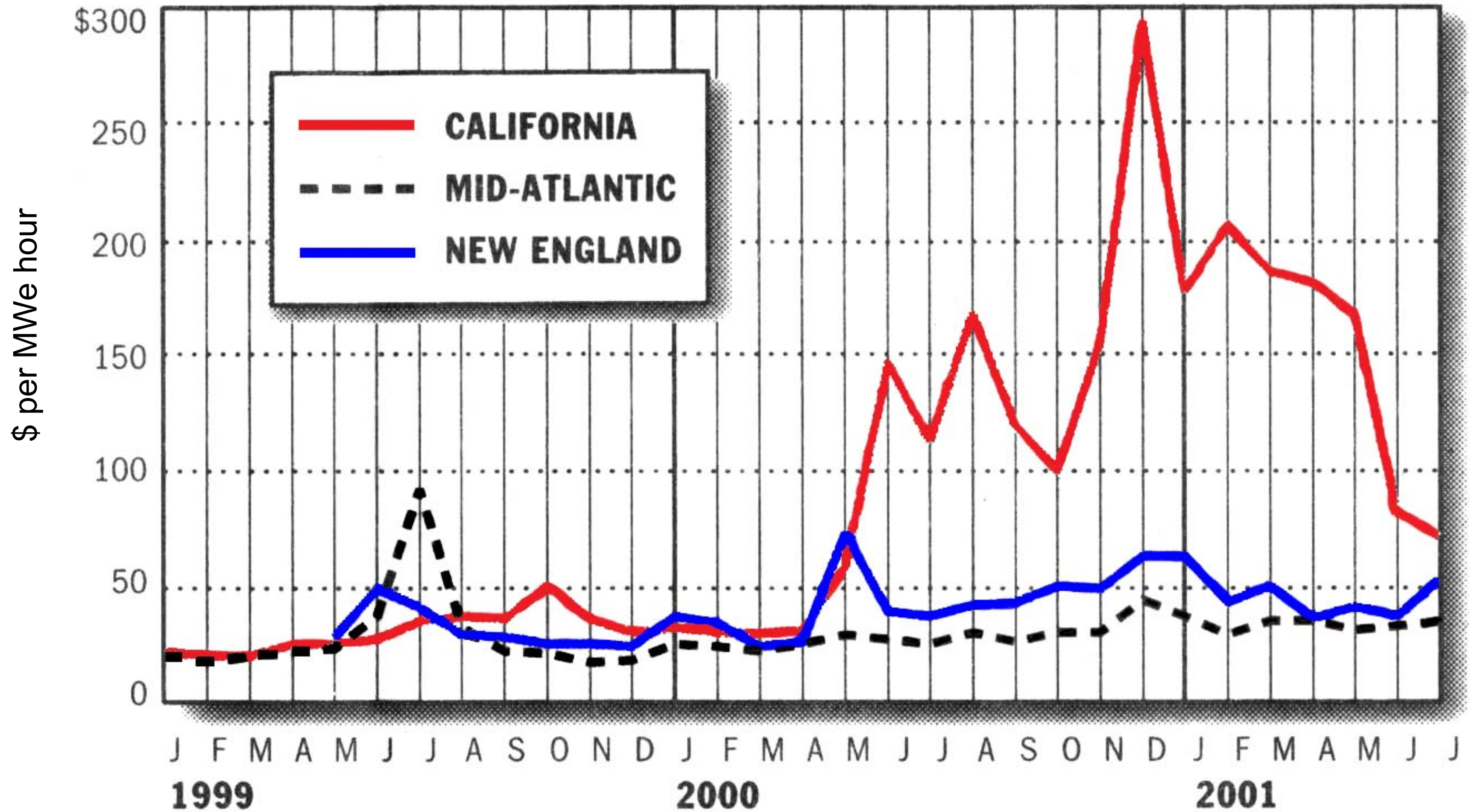
*Excludes transmission and distribution charges

ELECTRICITY'S NEW ERA

More Price Volatility....

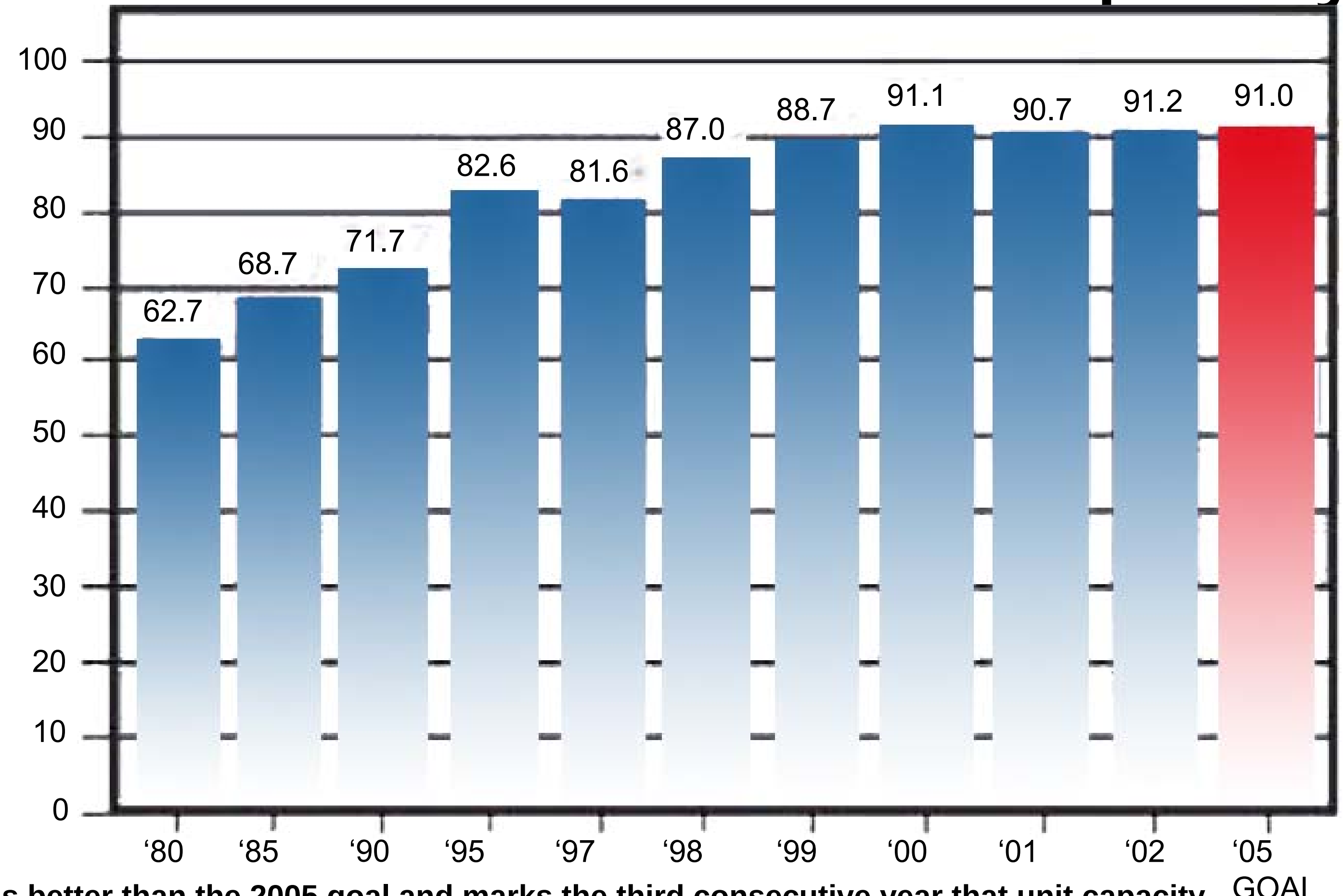
(Wall Street Journal 9/17/01)

Wholesale electricity costs in regional markets



Sources: CA ISO, PJM Interconnection, ISO New England

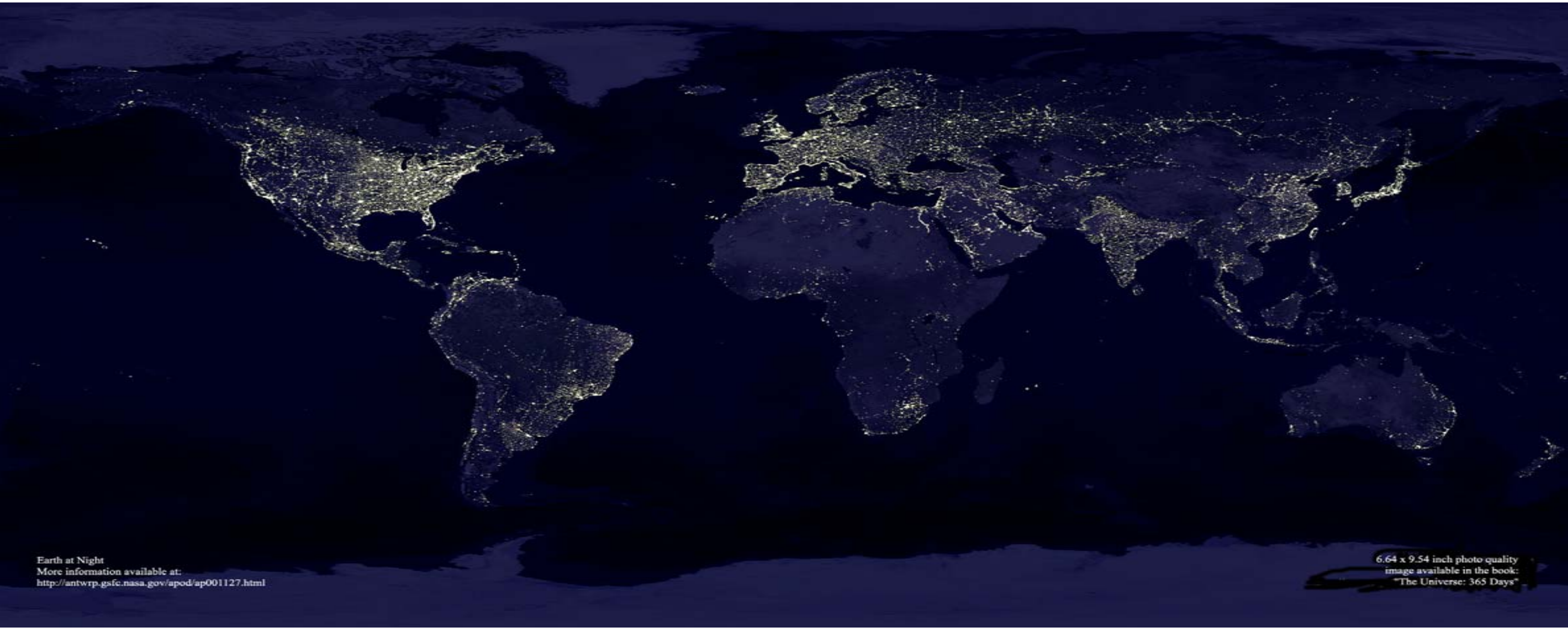
WANO Indicators : Nuclear Plants Unit Capacity,



The 2002 result is better than the 2005 goal and marks the third consecutive year that unit capacity tops 90%.

The indicator measures a plant's ability to stay on line and produce electricity. Plants with a high unit capability are successful in reducing unplanned outages and improving planned outages.

What does this picture tell you ?

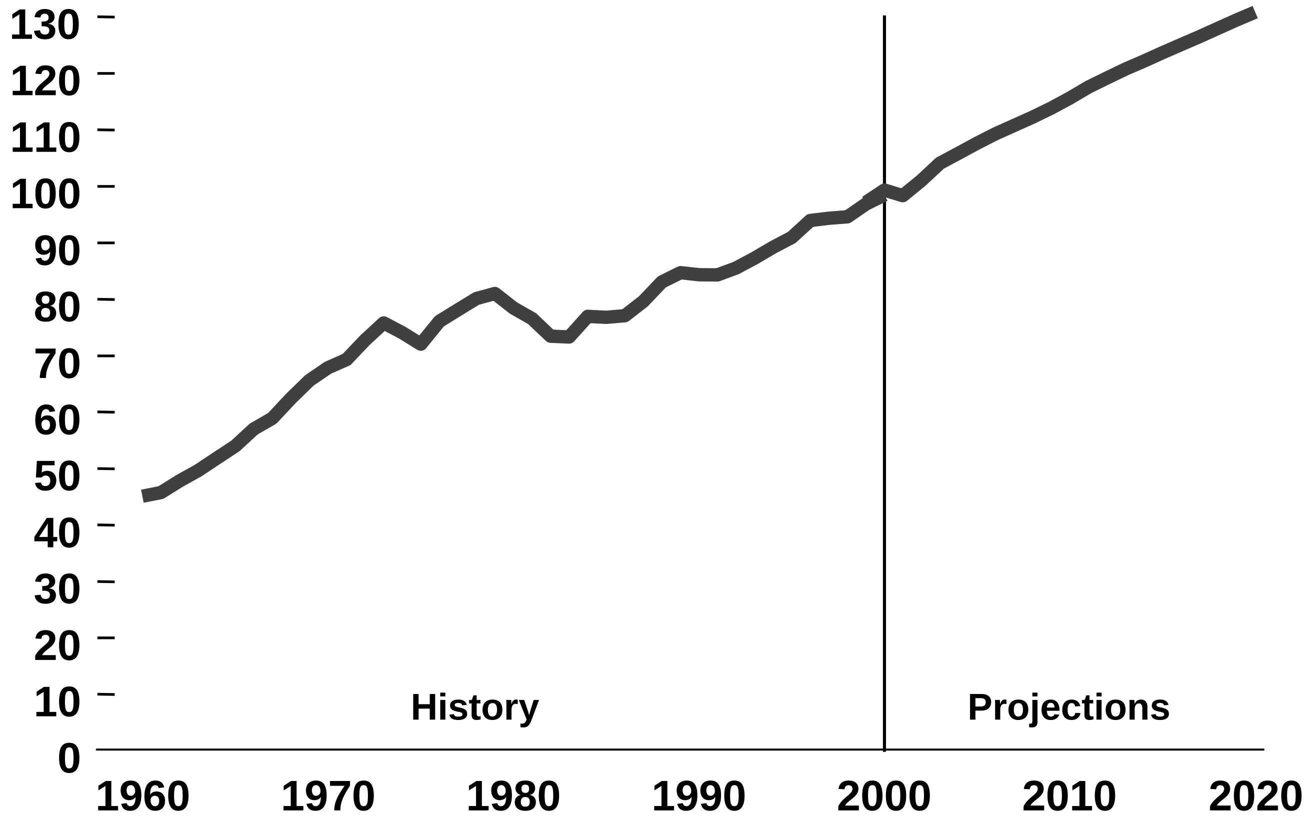


World Energy by Supply

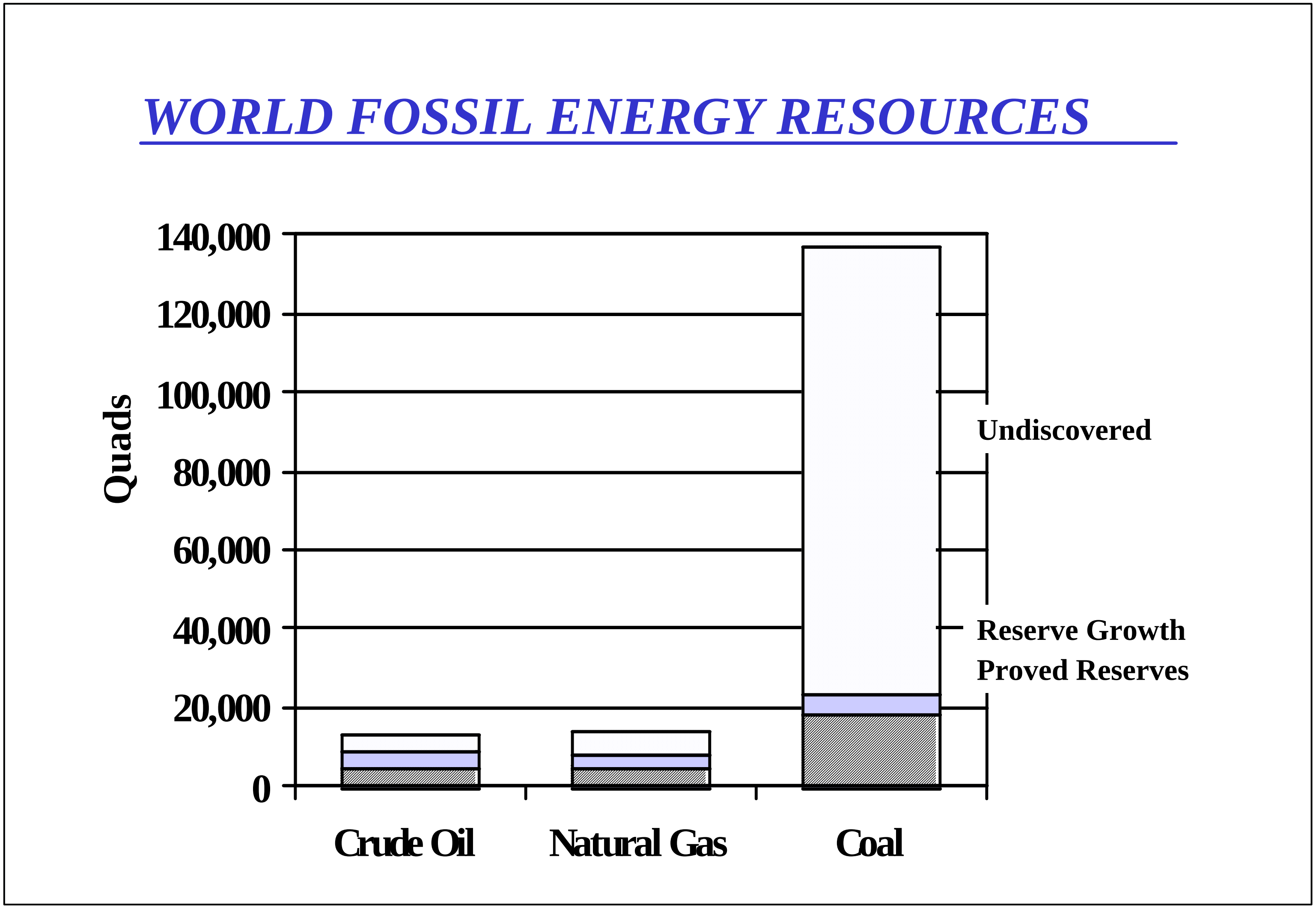
	World	OECD
Oil:	35%	41%
Coal:	23%	21%
Nat Gas:	21%	21%
Nuclear:	7%	11%
Wood+:	11%	3%
Hydro:	2%	2%
Other:	0.5%	0.7%

Other = (geo, wind, solar, etc)

US Primary Energy Consumption 1960-2020 (quadrillion Btu)

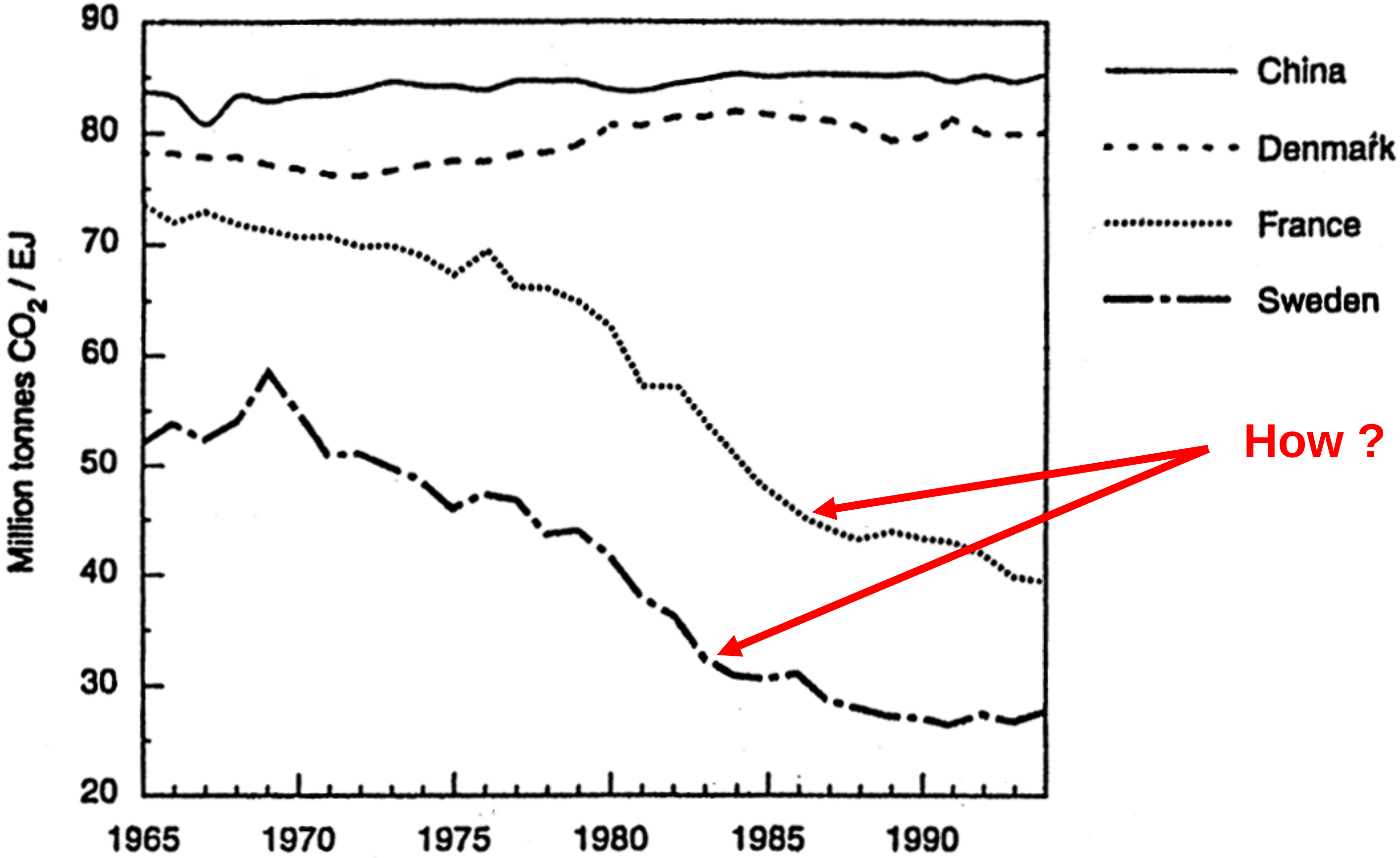


Hutzler, M.J. Annual Energy Outlook 2002. Energy Information Administration, 2002



- U.S. Geological Survey. World Petroleum Assessment 2000: Description And Results. DDS-60. Version 1. 2000.
- DOE EIA. International Energy Outlook-2001. March 2001.
- World Energy Council, 1998 Survey Of Energy Resources. 18th Edition. 1998.

CO_2 PER UNIT OF ENERGY



Source: BRITISH PETROLEUM, Statistical Review of World Energy, BP, London, 1996.

Examples of Greenhouse Gases Affected by Human Activities

	CO_2	CH_4	N_2O
Pre-industrial concentration	280 ppmv	700 ppbv	275 ppbv
Concentration in 1994	358 ppmv	1720 ppbv	312 ppbv[2]
Rate of concentration change[1]	1.5 ppmv/yr	10 ppbv/yr	0.8 ppbv/yr
Atmospheric lifetime (years)	50-200[a]	12[b]	120

ppmv = part per million volume; ppbv = part per billion volume

[1] The growth rates of CO_2, CH_4 and N_2O are averaged over the decade beginning in 1984.

[2] Estimated from 1992-1993 data.

[a] No single lifetime for CO2 can be defined because of the different rates of uptake by different processes.

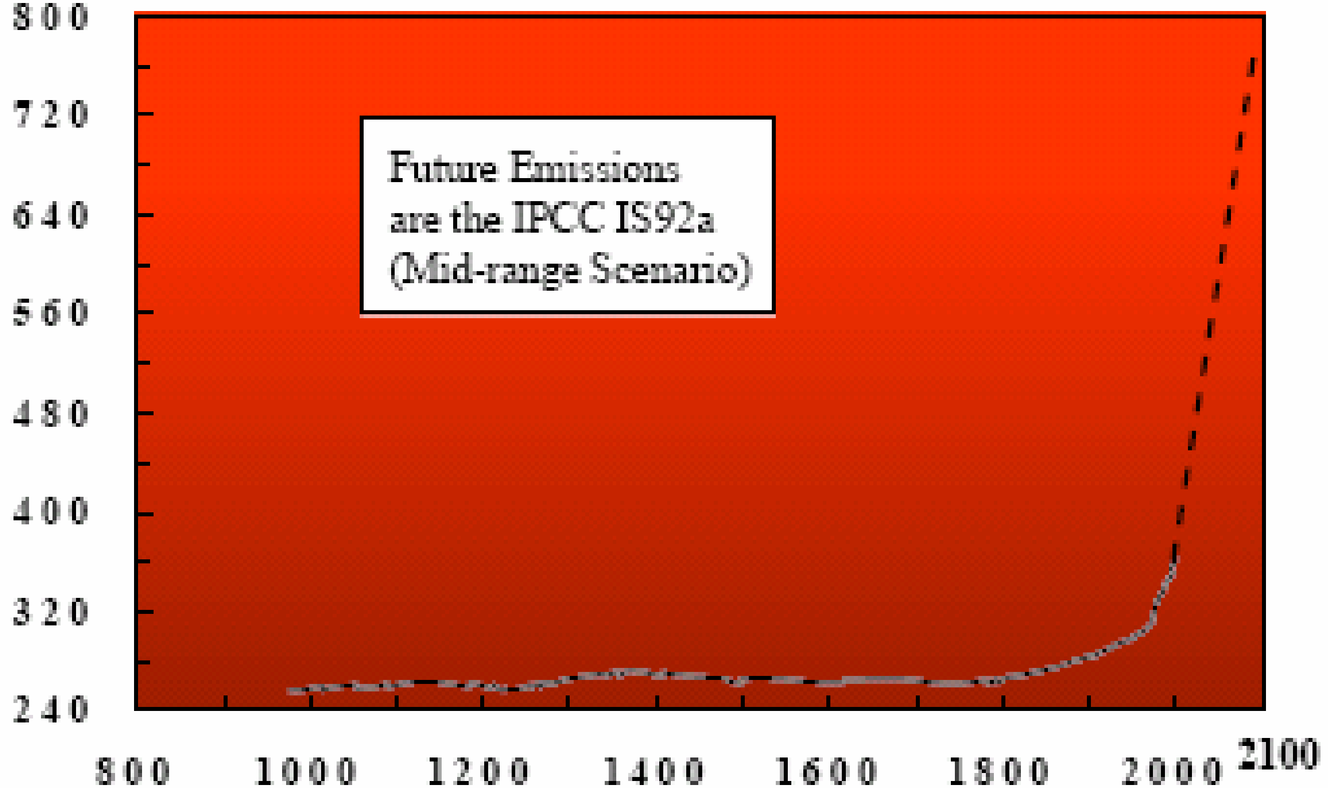
[b] Defined as an adjustment time which takes into account the indirect effects of methane on its own lifetime.

Source: IPCC, 1995

EPA

United States Environmental Protection Agency

Historical and Projected Future CO_2 Concentrations

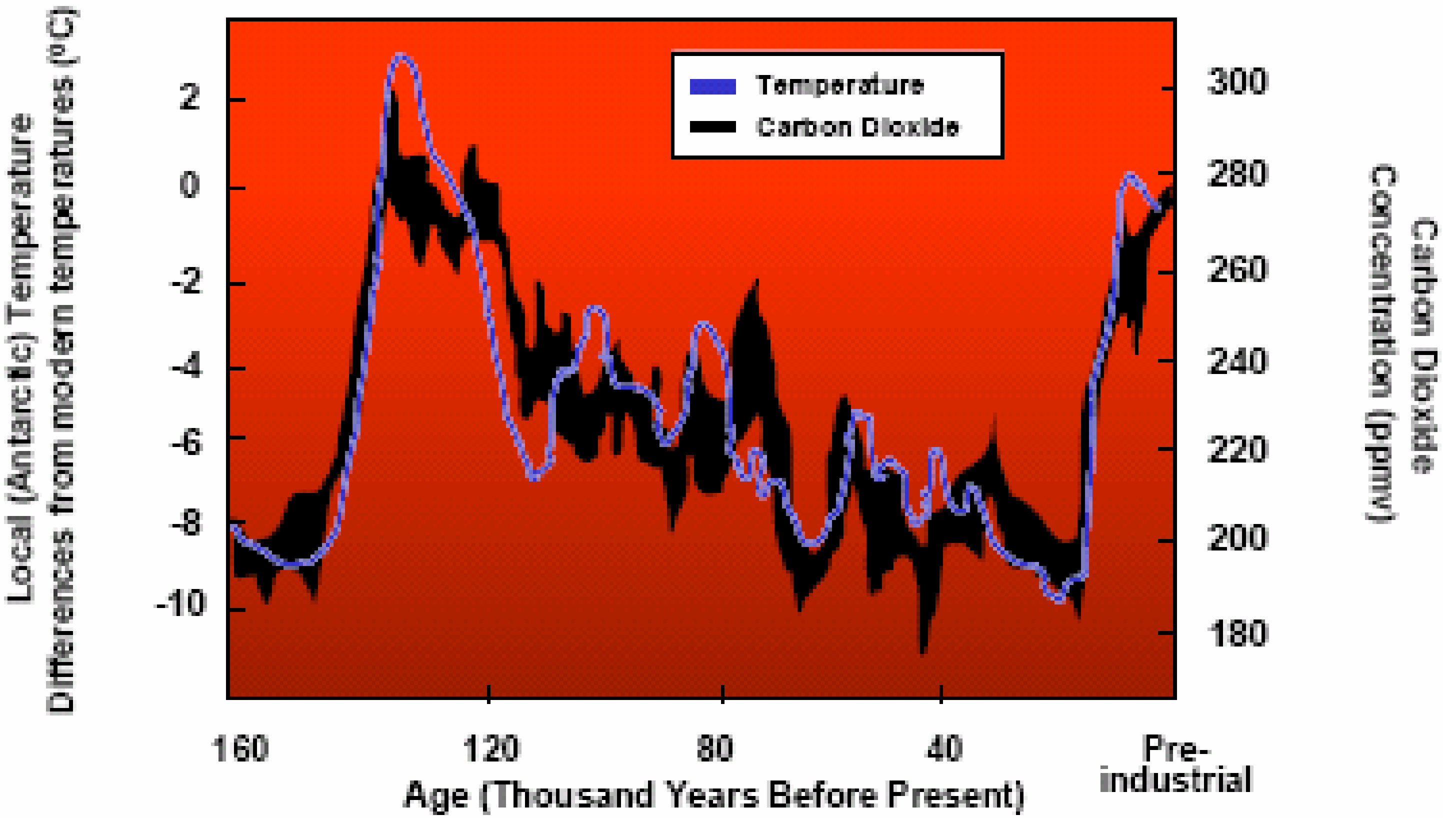


Derived from ice-core measurements (Siple and South Pole) and direct observation (Mauna Loa, Hawaii)
Source: Based on IPCC (1995)

EPA

United States Environmental Protection Agency

Local Temperature Change and CO_2 Concentrations Over the Past 160,000 Years



Derived from Antarctic ice cores

Source: Based on IPCC (1990)

EPA

United States Environmental Protection Agency

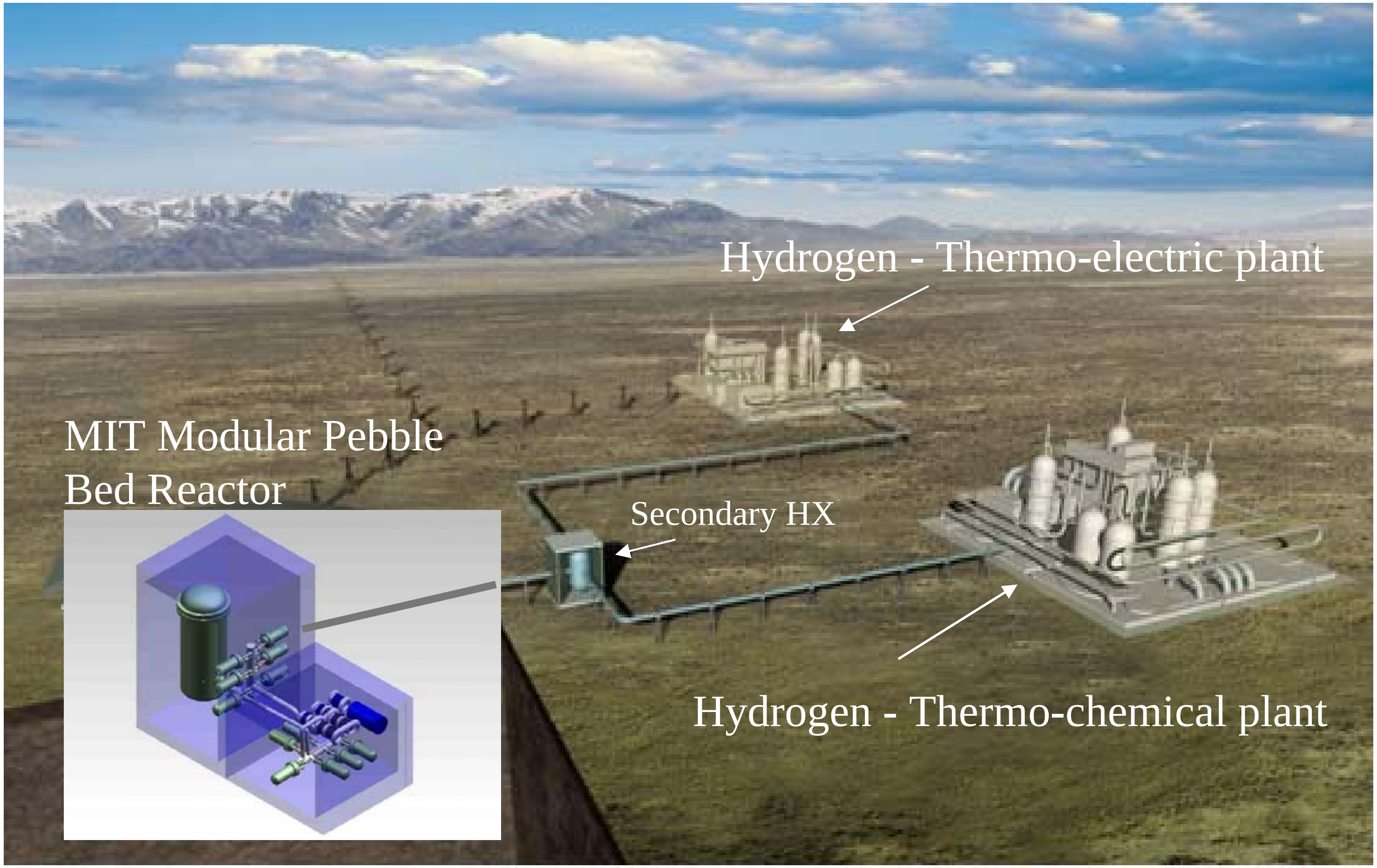
The “Next” Generation

- Next Generation Nuclear Plant (NGNP)
- Nuclear Hydrogen Production
- Pebble Bed Reactors – High Temperature Gas
- Risk Informed Design, Safety and Licensing

Next Generation Nuclear Plant

- High Temperature Gas
- Indirect Cycle
- Electric generation
- Hydrogen production
- Pebble bed reactor or block reactor?
- Built at the Idaho National Laboratory

Next Generation Nuclear Plant



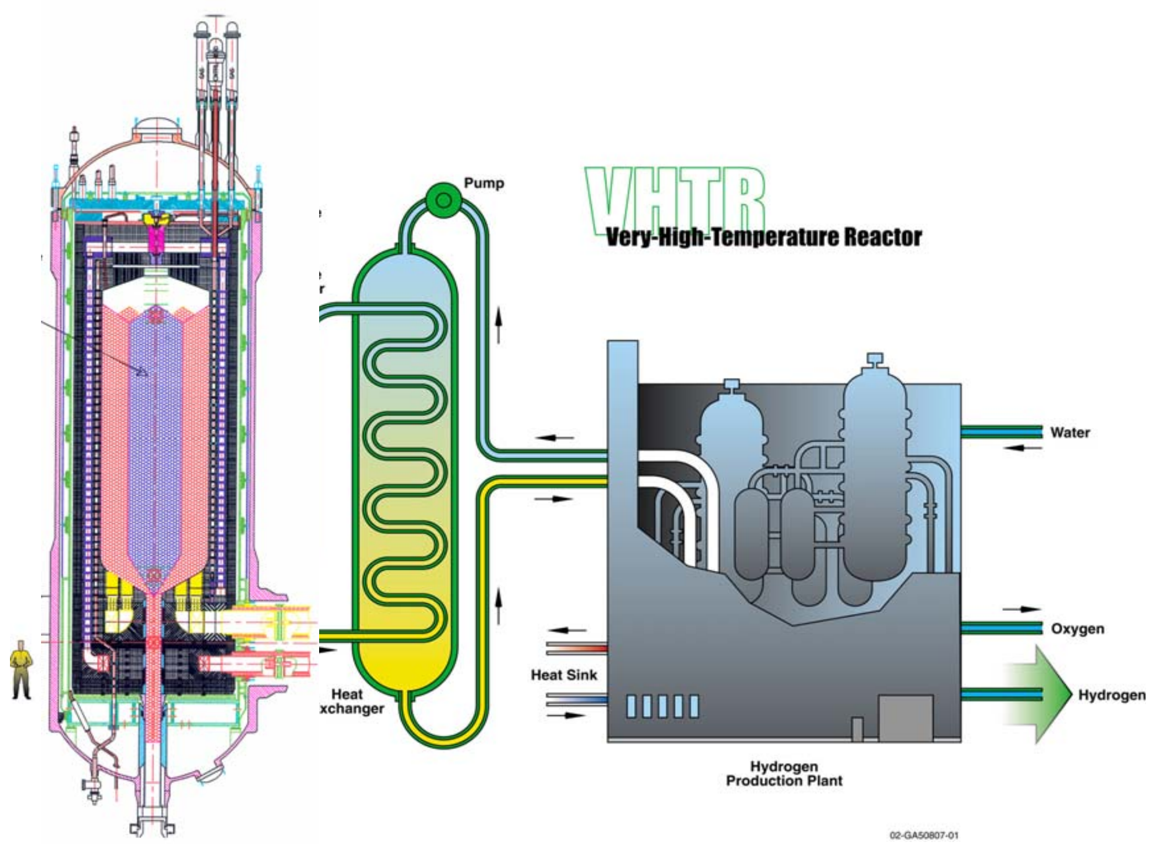
Very-High-Temperature Reactor (VHTR)

Characteristics

- Helium coolant
- 1000°C outlet temperature
- Water-cracking cycle

Benefits

- Hydrogen production
- High degree of passive safety
- High thermal efficiency
- Process heat applications

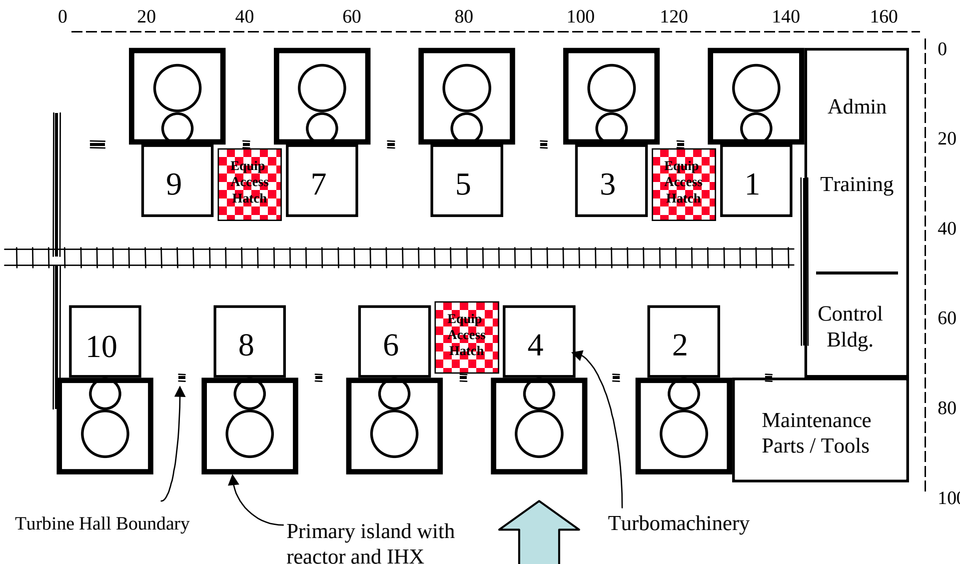


U.S. Product Team Leader: Dr. Finis Southworth (INEEL)

1150 MW Combined Heat and Power Station

Ten-Unit VHTR Plant Layout (Top View)

(distances in meters)

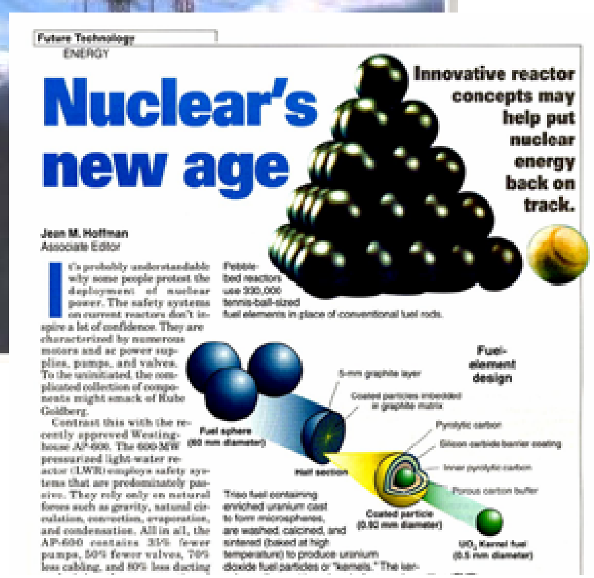


VHTR Characteristics
- Temperatures > 900 C
- Indirect Cycle
- Core Options Available
- Waste Minimization

Oil Refinery

Hydrogen Production

Desalinization Plant



Future Technology
ENERGY

Nuclear's new age

Innovative reactor concepts may help put nuclear energy back on track.

Jean M. Hoffman
Associate Editor

It's probably understandable why some people protest the deployment of nuclear power. The safety systems on current reactors don't inspire a lot of confidence. They are characterized by numerous motors and ac power supplies, pumps, and valves. To the uninitiated, the complicated collection of components might smack of Rube Goldberg.

Contrast this with the recently approved Westinghouse AP-600. The 600-MW pressurized light-water reactor (LWR) employs safety systems that are predominately passive. They rely only on natural forces such as gravity, natural circulation, convection, evaporation, and condensation. All in all, the AP-600 contains 35% fewer pumps, 50% fewer valves, 70% less cabling, and 80% less ducting

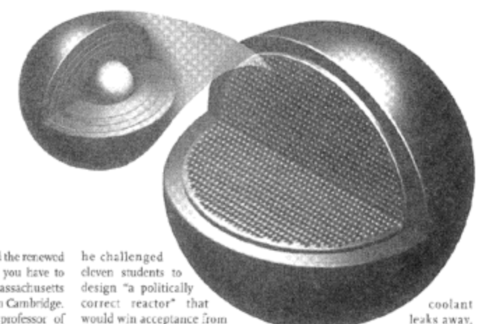
Pebble-bed reactors use 330,000 tennis-ball-sized fuel elements in place of conventional fuel rods.

Triso fuel containing enriched uranium cast to form microspheres, are washed, calcined, and sintered (baked at high temperature) to produce uranium dioxide fuel particles or "kernels." The ser-

The Politically Correct NUKE

MIT Students help design a nuclear power plant that they hope will revive the industry.

by Charles Wardell



Above right: A "pebble" (about eight-ball size) containing 10,000 uranium dioxide particles the size of a pencil point, each coated with several layers of graphite and a silicon carbide outer shell (inset). Though the pebbles heat to more than 1,000°C, the coatings trap the radiation inside. The particles decay within 250,000 years, but the graphite ball maintains its integrity for more than one million years.

To truly understand the renewed buzz for nuclear, you have to travel to the Massachusetts Institute of Technology in Cambridge. Here, Andrew Kadak, professor of nuclear engineering, holds two billiard-size balls that many believe represent the future of nuclear energy. The balls are the "pebbles" in something called a pebble bed reactor, a new type of plant that proponents say is safer and more efficient than current plants. It could even crank out electricity for less than a gas-fired plant, savings that would presumably be passed on to you. More important, considering our anxiety toward nuclear energy, it's immune to meltdowns. The technology could be implemented, possibly at Three Mile Island, within five years.

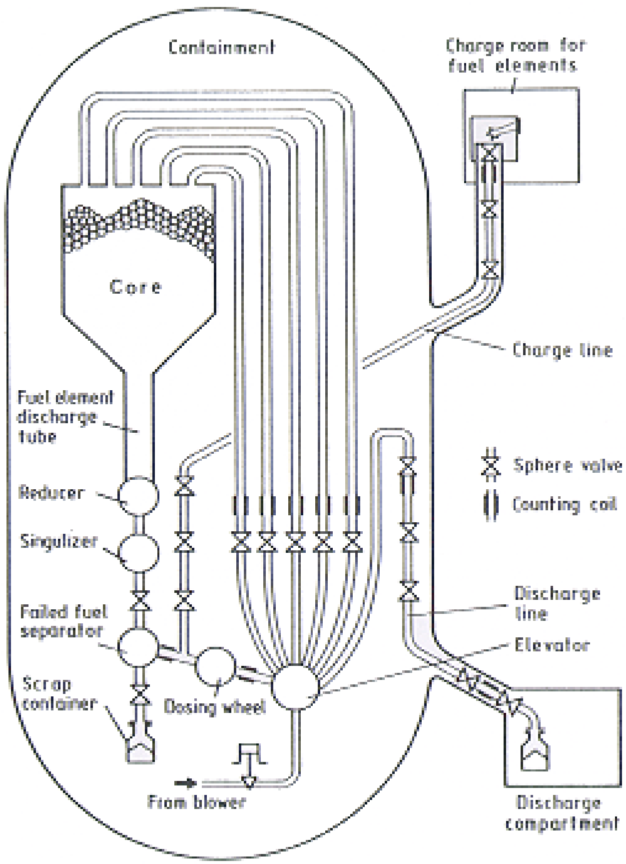
When Kadak, formerly vice president of the American Nuclear Society, came to MIT in 1997, nuclear power seemed doomed. So in January 1998, he challenged eleven students to design "a politically correct reactor" that would win acceptance from regulators and the public while giving gas a run for its energy-generating money.

All existing US commercial reactors are "light water" reactors. They're powered by half-inch cylindrical pellets of uranium—like cutoffs from a 1/2-inch dowel—stacked up in 14-foot-long metal rods. Hundreds of rods are lowered into a water-filled reactor core. The uranium atoms give off neutrons, some of which crash into other uranium atoms, splitting them, generating heat, and knocking free more atom-splitting neutrons—the process known as fission. The water in the core carries the heat away to drive an electric turbine.

Kadak's students rejected light-water technology for this reason: If the coolant leaks away, the core heats up enough to melt. Instead, they found something they considered safer: a pebble bed research reactor that had run for twenty-two years in Germany ("until Chernobyl came along and Germany got out of nuclear," Kadak says). It relied on fission too, but was fueled by eight-ball-sized pebbles, and rather than water coolant, it used helium gas.

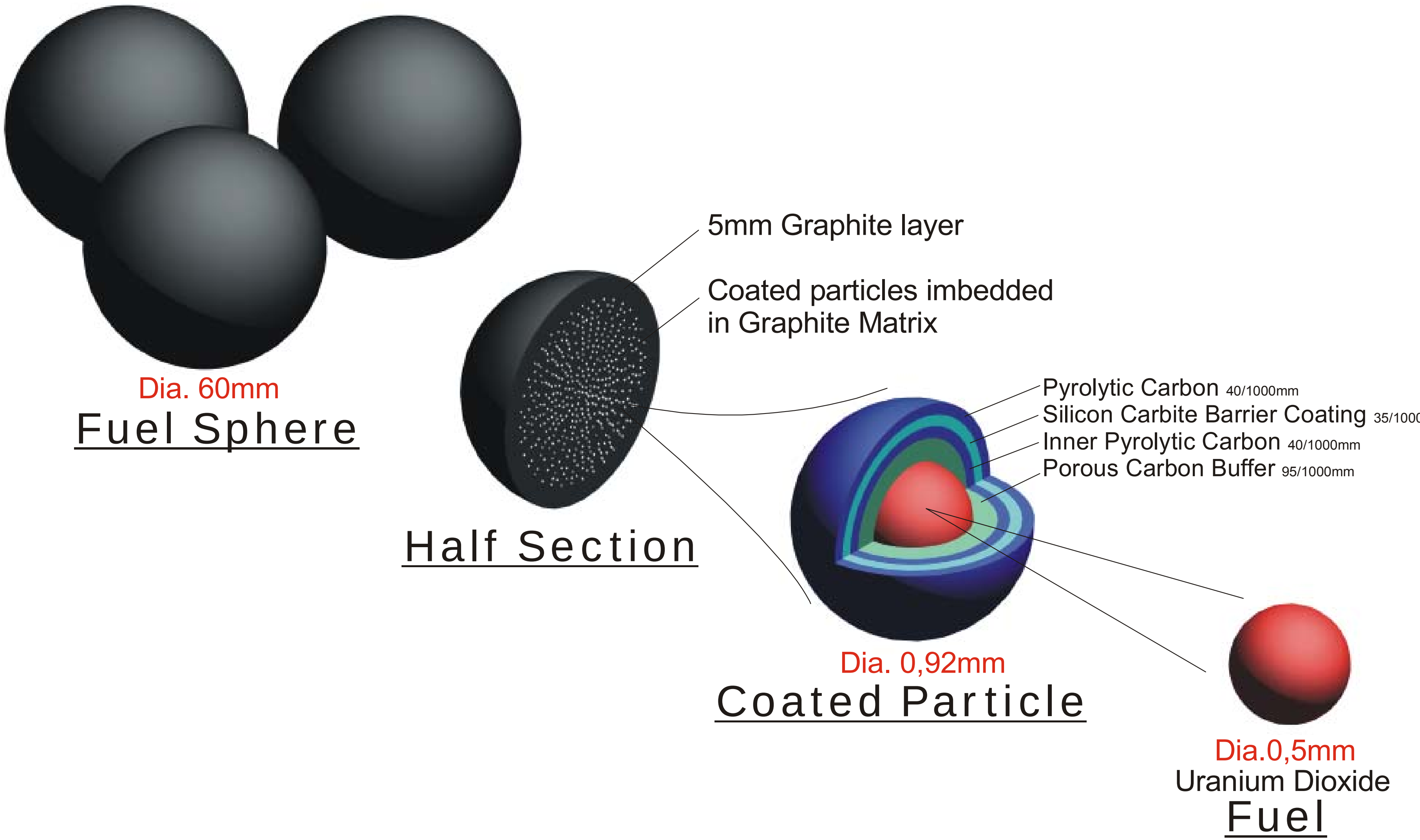
The main safety feature is the fuel itself. Each pebble consists of roughly 10,000 "microspheres" of uranium dioxide the size of a pencil point. Each is in turn coated with several layers of graphite, and a silicon carbide outer shell. While fission heats the pebbles to as much as 1,100°C, the coatings trap all radioactivity inside. Once the

What is a Pebble Bed Reactor ?

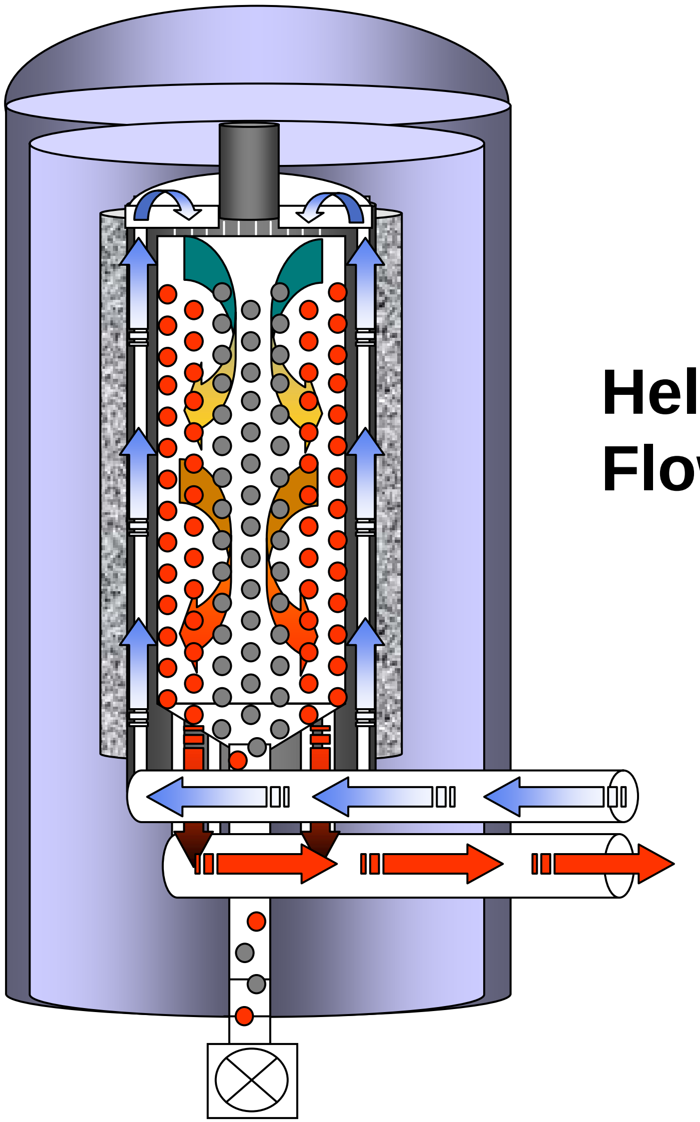


- 360,000 pebbles in core
- about 3,000 pebbles handled by FHS each day
- about 350 discarded daily
- one pebble discharged every 30 seconds
- average pebble cycles through core 10 times
- Fuel handling most maintenance-intensive part of plant

FUEL ELEMENT DESIGN FOR PBMR



Reactor Unit



Helium Flowpath

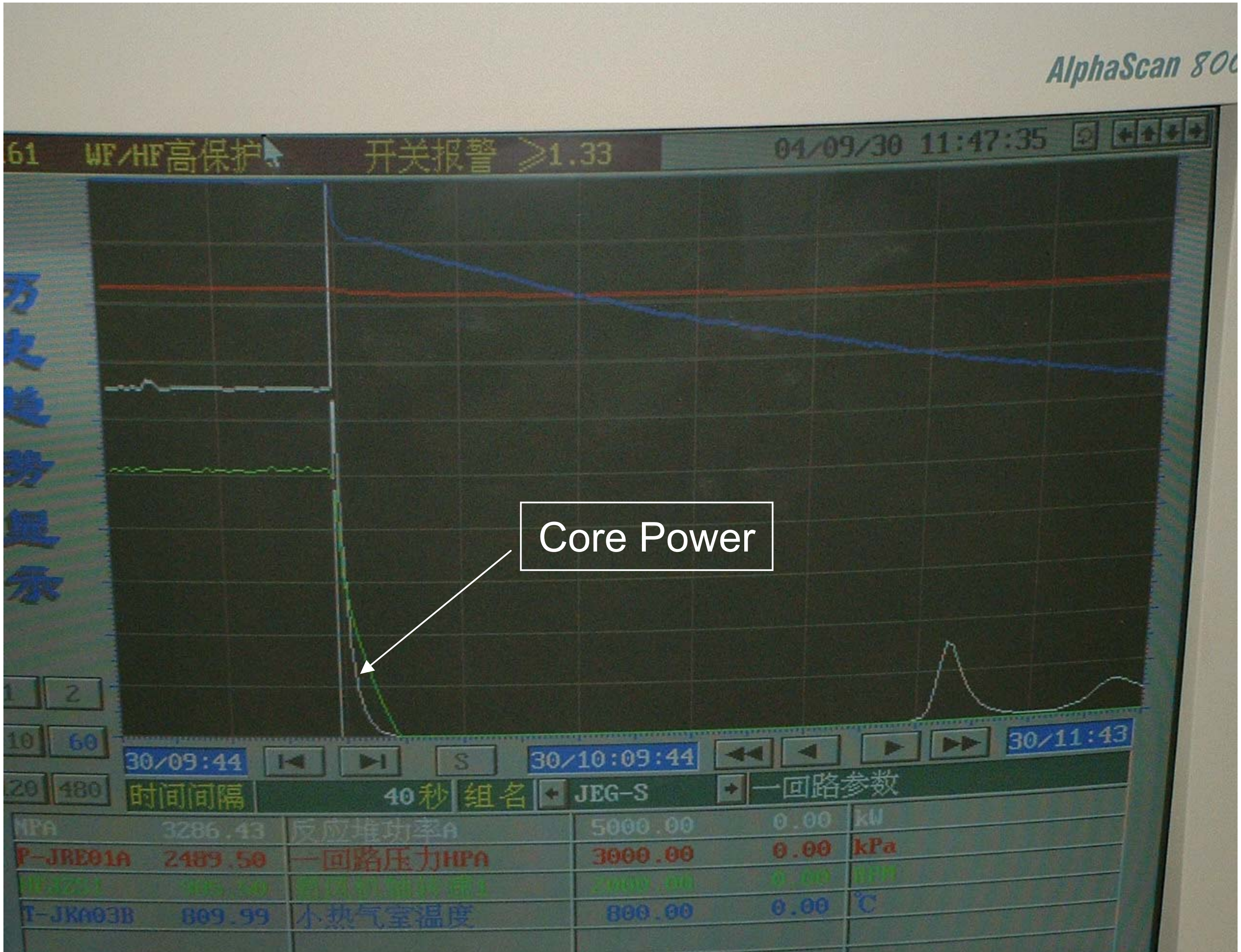
AVR: Jülich

15 MWe Research Reactor

HTR- 10 China
First Criticality Dec.1, 2000

Safety of Pebble Beds

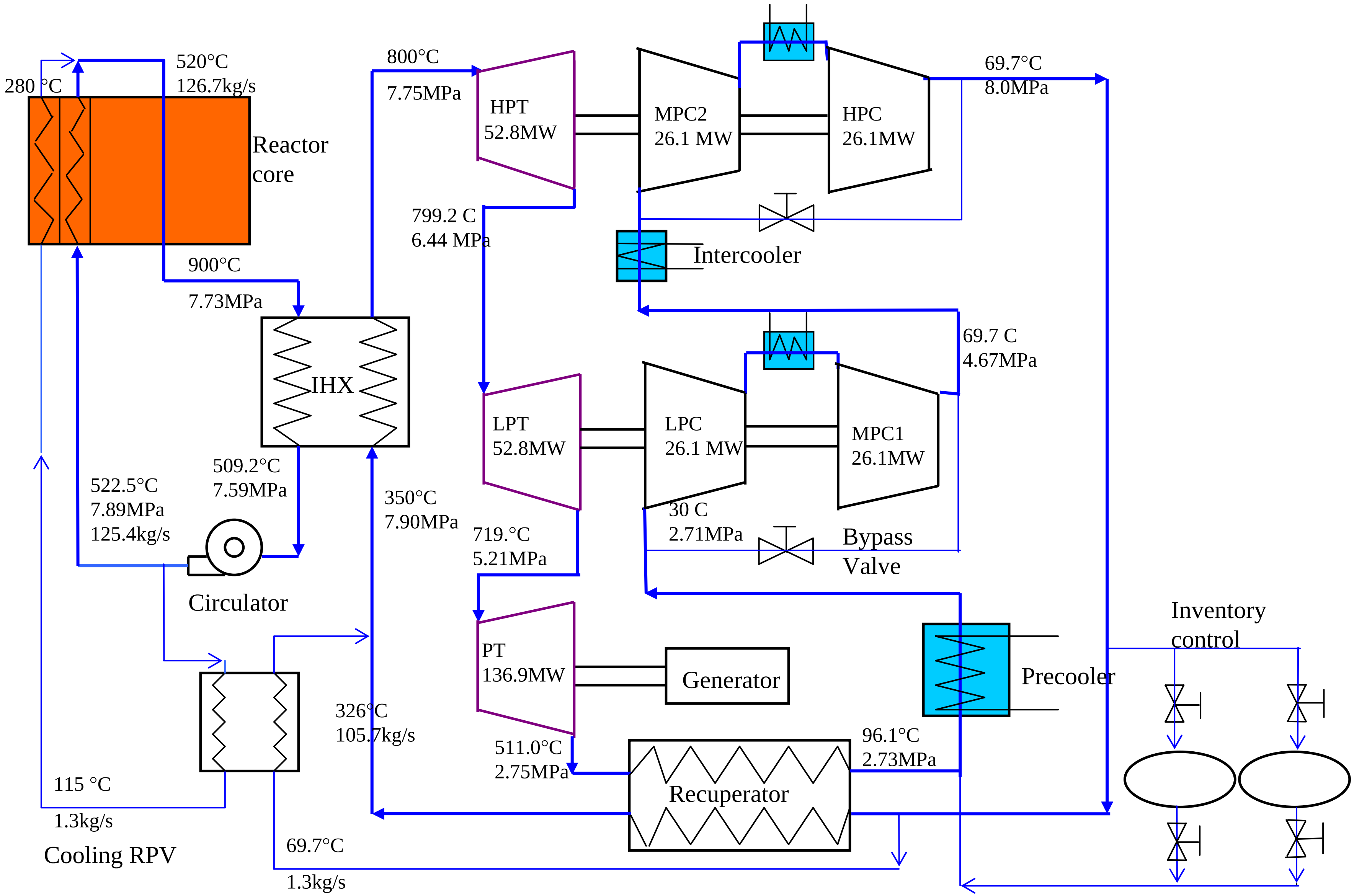
Shutoff all Cooling, Isolate Steam Generator, Prevent Auto Shutdown

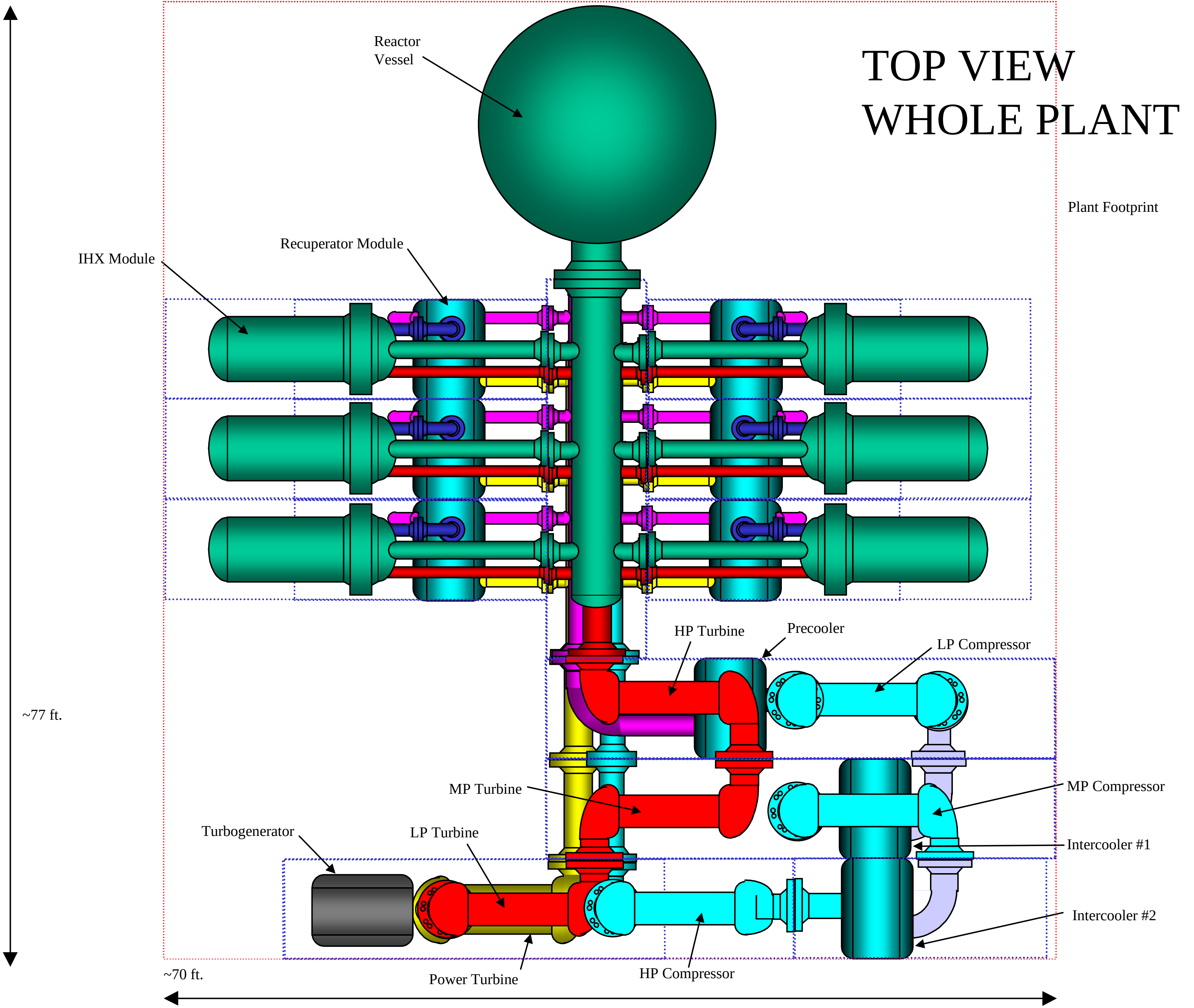


Features of MIT MPBR Design

Thermal Power	250 MW
Gross Electrical Power	132.5 MW
Net Electrical Power	120.3 MW
Plant Net Efficiency	48.1% (Not take into account cooling IHX and HPT. if considering, it is believed > 45%)
Helium Mass flowrate	126.7 kg/s
Core Outlet/Inlet T	900°C/520°C
Cycle pressure ratio	2.96
Power conversion unit	Three-shaft Arrangement

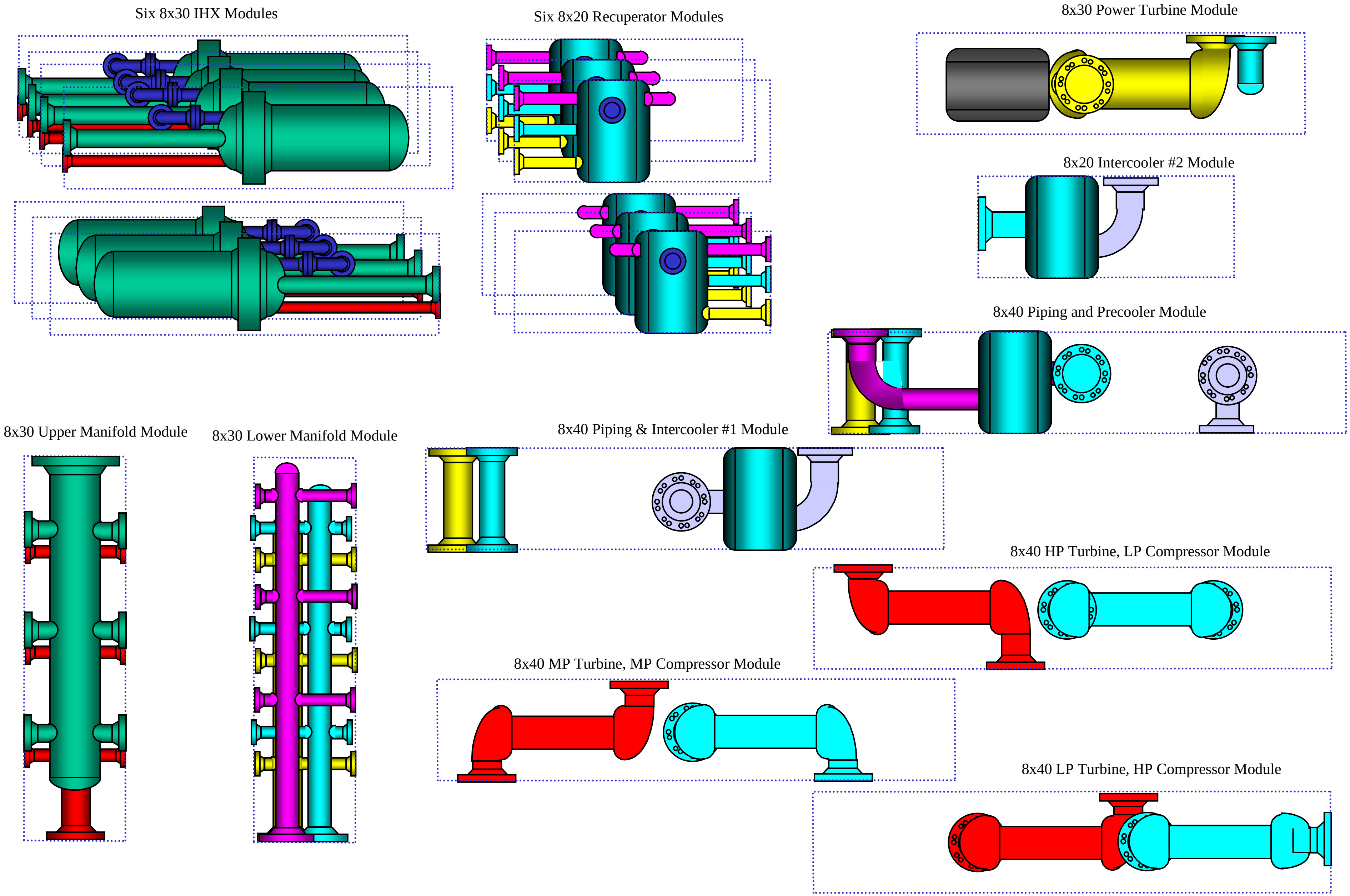
Current Design Schematic



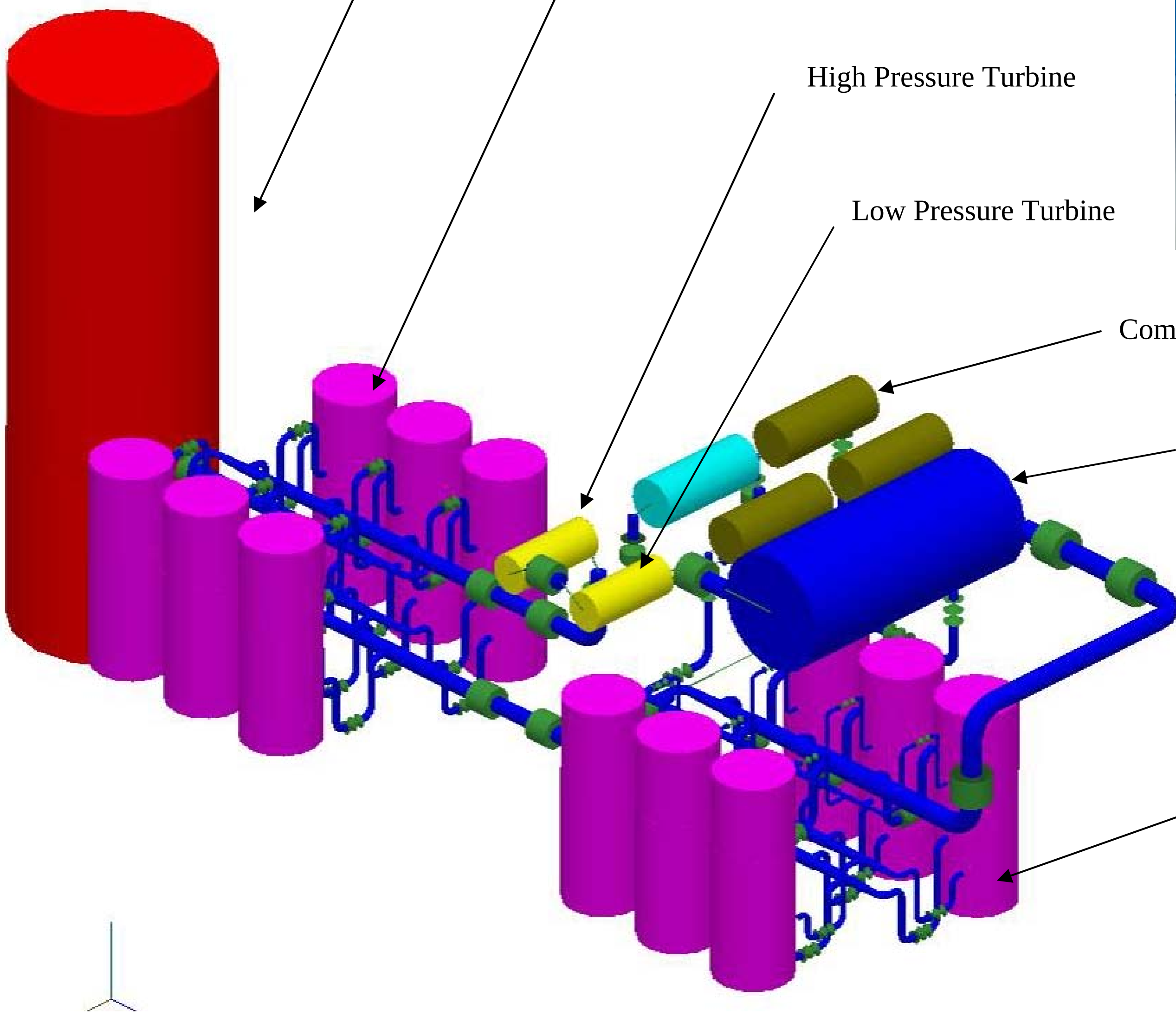

TOP VIEW
WHOLE PLANT
Reactor
Vessel
Plant Footprint
Recuperator Module
IHX Module
HP Turbine
Precooler
LP Compressor
~77 ft.
MP Turbine
MP Compressor
Turbogenerator
LP Turbine
Intercooler #1
Intercooler #2
~70 ft.
Power Turbine
HP Compressor

PLANT MODULE SHIPPING BREAKDOWN

Total Modules Needed For Plant Assembly (21): Nine 8x30 Modules, Five 8x40 Modules, Seven 8x20 Modules

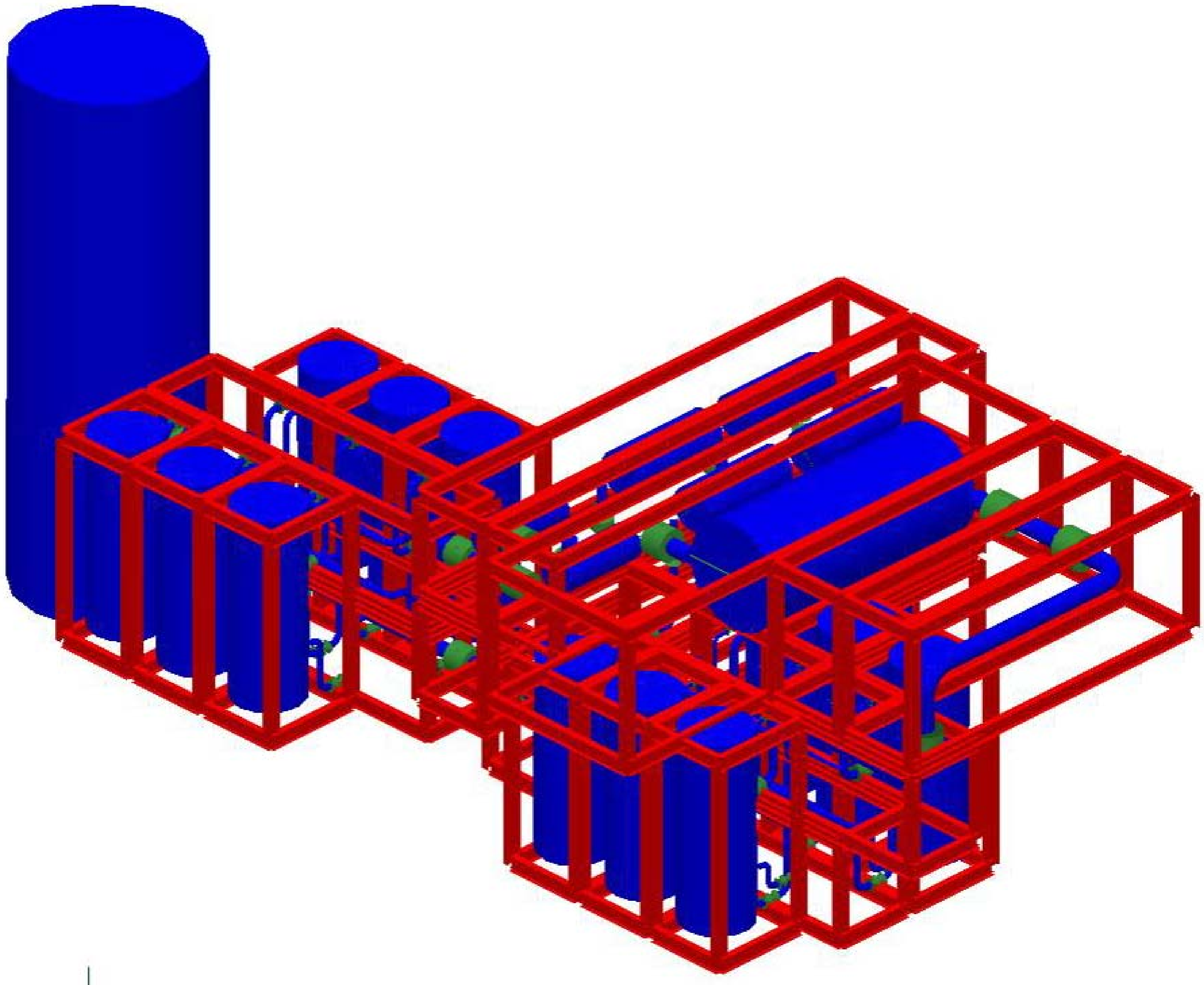


Present Layout

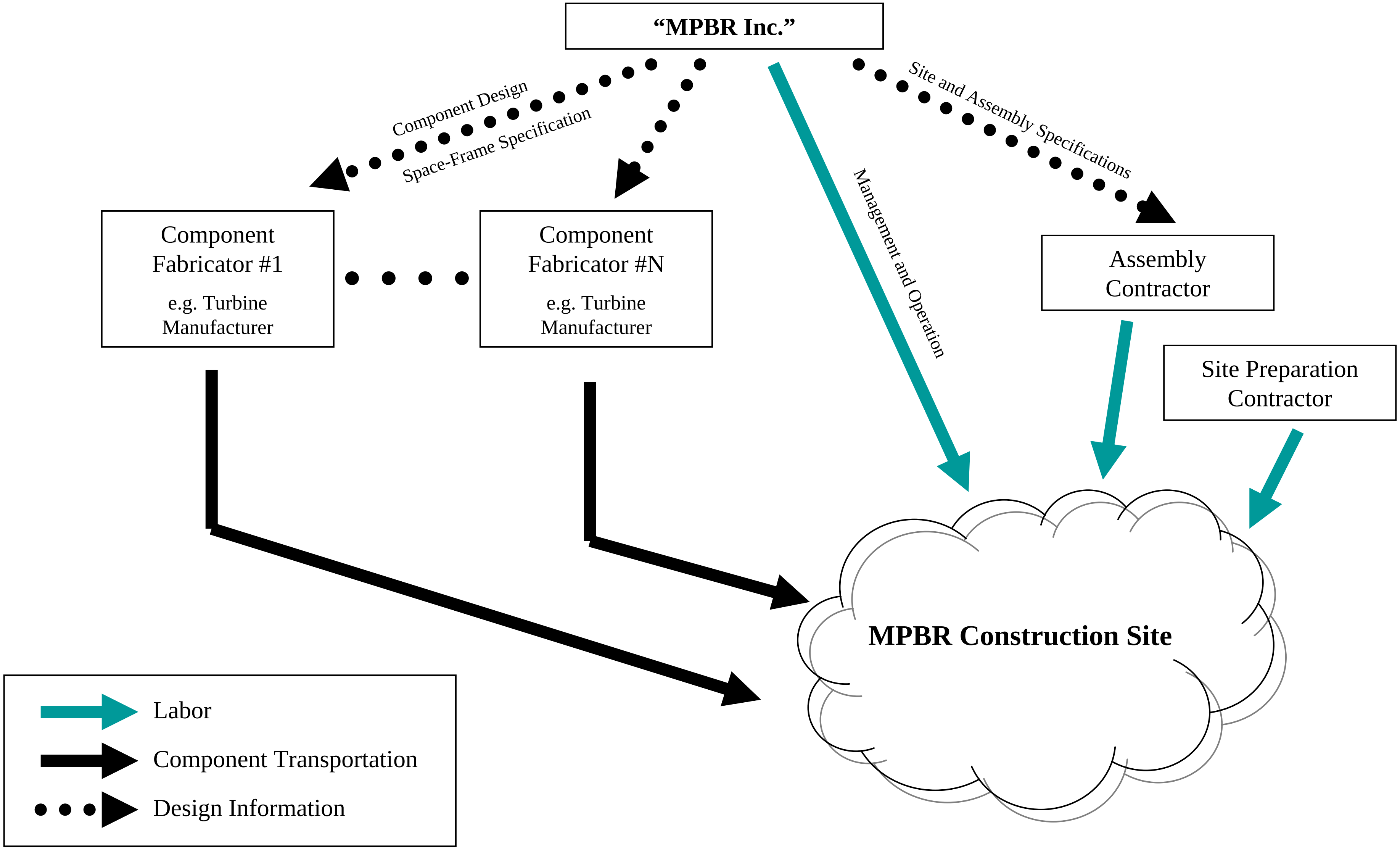


Space-Frame Concept

- Standardized Frame Size
- 2.4 x 2.6 x 3(n) Meter
- Standard Dry Cargo Container
- Attempt to Limit Module Mass to ~30t / 6m
  - ISO Limit for 6m Container
  - Stacking Load Limit ~190t
  - ISO Container Mass ~2200kg
  - Modified Design for Higher Capacity—~60t / 12m module
- Overweight Modules
  - Generator (150-200t)
  - Turbo-Compressor (45t)
  - Avoid Separating Shafts!
  - Heavy Lift Handling Required
  - Dual Module (12m / 60t)
- Stacking Load Limit Acceptable
  - Dual Module = ~380T
    - Turbo-generator Module <300t
- Design Frame for Cantilever Loads
  - Enables Modules to be Bridged
- Space Frames are the structural supports for the components.
- Only need to build open vault areas for space frame installation - RC & BOP vault
- Alignment Pins on Module Corners
  - High Accuracy Alignment
  - Enables Flanges to be Simply Bolted Together
- Standardized Umbilical Locations
  - Bus-Layout of Generic Utilities (data/control)



Distributed Production Concept



Distributed Production Concept - Virtual Factory !

- Evolution of the “Reactor Factory” Concept
- There Is ***NO*** Factory
  - Off-load Manufacturing Capital Expense to Component Suppliers
    - Decrease follow-through capital expense by designing to minimize new tooling—near COTS
    - Major component fabricators become mid-level integrators—following design delivered from HQ
  - Reduces Transportation Costs
    - Component weight ≈ Module weight: Why Transport It Twice?
  - Enables Flexible Capitalization
    - Initial systems use components purchased on a one-off / low quantity basis
    - Once MPBR demand established, constant production + fabrication learning curve lower costs

- Site / Building Design Does Not Require Specialized Expertise
  - Enables Selection of Construction Contractors By Location / Cost
  - Simplified Fabrication Minimizes “MPBR Inc.” Workforce Required
- Simple Common Space-Frame Design
  - Can be Easily Manufactured By Each Individual Component Supplier
  - Or if necessary sub-contracted to generic structural fabricator
- Modern CAD/CAE Techniques Enable High First-Fit Probability—Virtual “Test-Fit”

Challenges

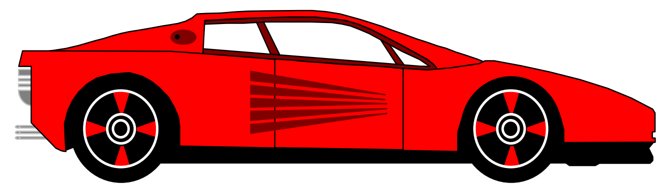
- Unless the cost of new plants can be substantially reduced, new orders will not be forthcoming.
- The novel truly modular way of building plants may be the right way to go – shorter construction times.
- Smaller units may be cheaper than larger units – economies of production may trump the economies of scale when financial risks are considered.
- The bottom line is cents/kwhr not $/kwe !!

Risk Informed Design, Safety and Licensing

- Use PRA principles in design of CO_2 gas reactor – avoid problems
- Technology neutral risk informed safety standards
- “License by test” regulatory approach for innovative reactors

What About Transportation ?

- Fuel Cells ?
- Electric Cars ?
- Solar Electric Cars
- Natural Gas ?
- Combo-Cars
- Hydrogen Powered



Where do we get the hydrogen ?

The Hydrogen Economy Has Started

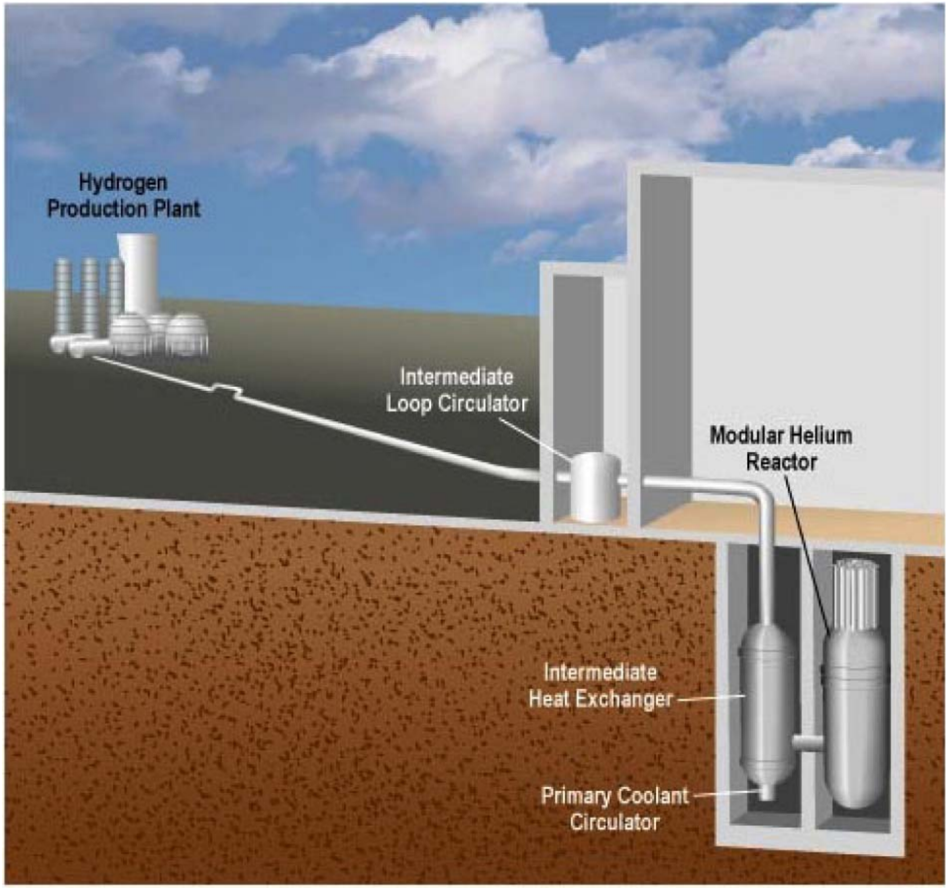
- World wide 200 GWt produced.
- US use now 11 million tons/y (48 GWt)
- 95% produced from Methane
  - Consumes 5% of natural gas usage
  - Not CO_2 free: 74 M tons of CO_2/y
- 50% is used in fertilizer,
  37% in oil industries
- 97% produced near use site, no distribution infrastructure
- ~ 10%/y growth
  ➔ X 2 by 2010, X 4 by 2020
- Hydrogen Economy will need
  X 18 current for transportation
  X 40 for all non-electric

How Can We Get Hydrogen from Nuclear Energy?

- Electricity – Electrolysis ES
  - Current technology but not efficient
- Thermal source for SMR
  - Near term technology - does not eliminate CO_2 emissions
- Heat – Thermo-chemical TC
  - R&D scale technology, high temperature catalyzed reactions for water splitting
  - Current Technology: Steam Methane Reforming, reduces GHG emissions by a factor of 2
- Electricity/Heat – high temp. steam electrolysis HTES
  - R&D scale technology
  - Reversed fuel cellss

Candidate Nuclear Reactors for Thermochemical and Electrical Water Splitting

- Current commercial reactors are too low temperature for efficient production.
- Helium, heavy metal, molten salt are the DOE candidates; helium gas-cooled most developed
- Modular Helium Reactors are suited for TC production of hydrogen by either water splitting or methane reforming.
- British Advanced Gas Reactors, cooled by CO_2, if raised in pressure and equipped with gas turbines are also good candidates for HTES.



H_2-MHR

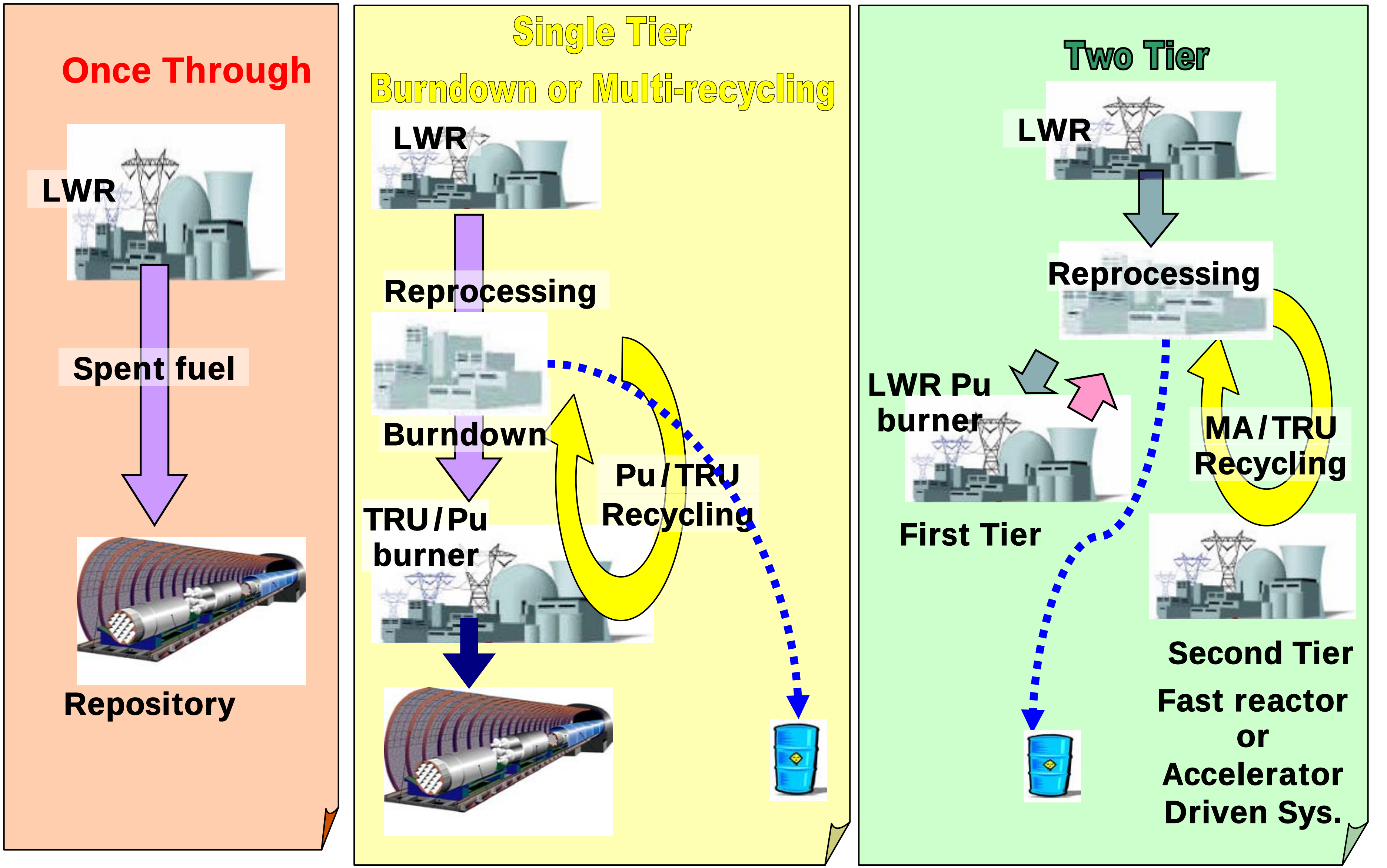
Advantages of Nuclear Energy

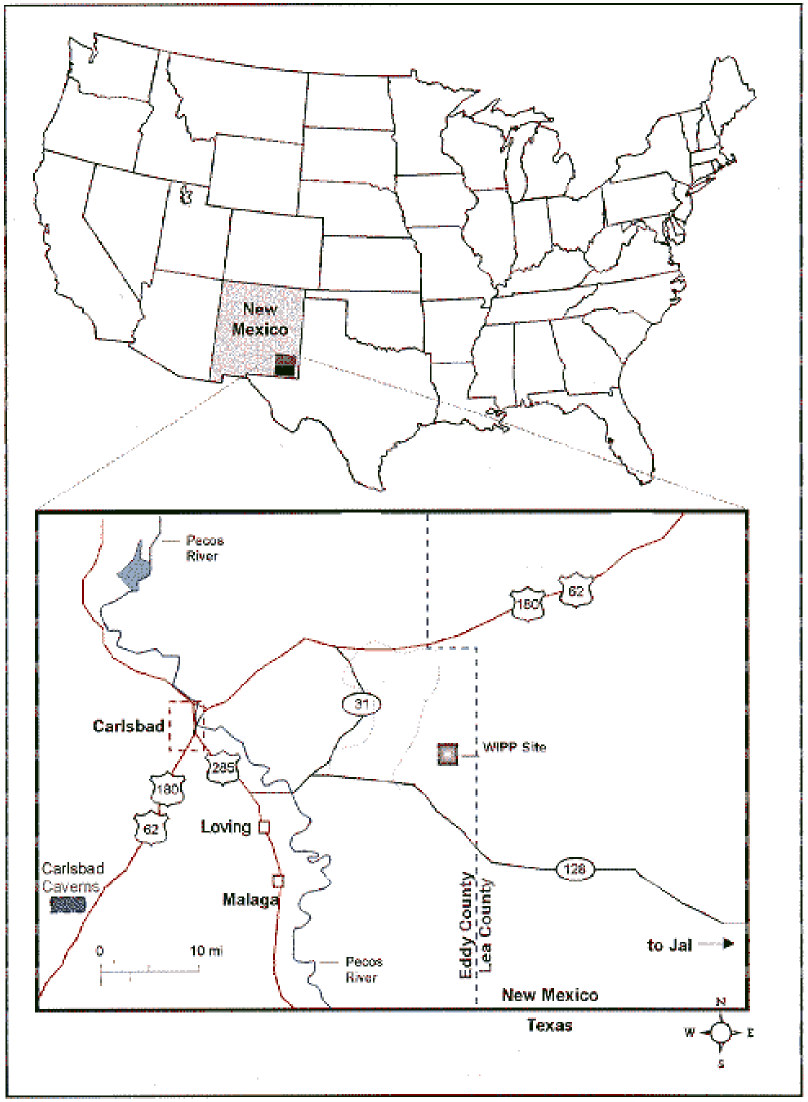
- Long term domestic and internationally stable supply of uranium: 50 to 100 years per today's technology, 5000 years with breeding. Ocean supplies are 100 times more. Thorium can add 15,000 years.
- No air pollution by toxic gases or particulates
- No emissions of global warming gases
- Has 1/5000 smaller solid waste volume than coal. Needs one football field size repository for all wastes from 100 operating reactors
- US Reliability record of late is impressive. Almost 3000 reactor years have been logged. One core melted, but did not harm public.

But, What about the Waste ?

- Geological Disposal
- Yucca Mountain Nevada
- 10,000 to peak dose at 700,000 year standard – new EPA standard
- 15 millirem/yr at 10,000 years from all sources – What do we get in Cambridge??
- Is it operating – NO
- Will it be hard to License – YES
- Do we have an operating geological waste repository in the US - YES

Fuel Cycle Options

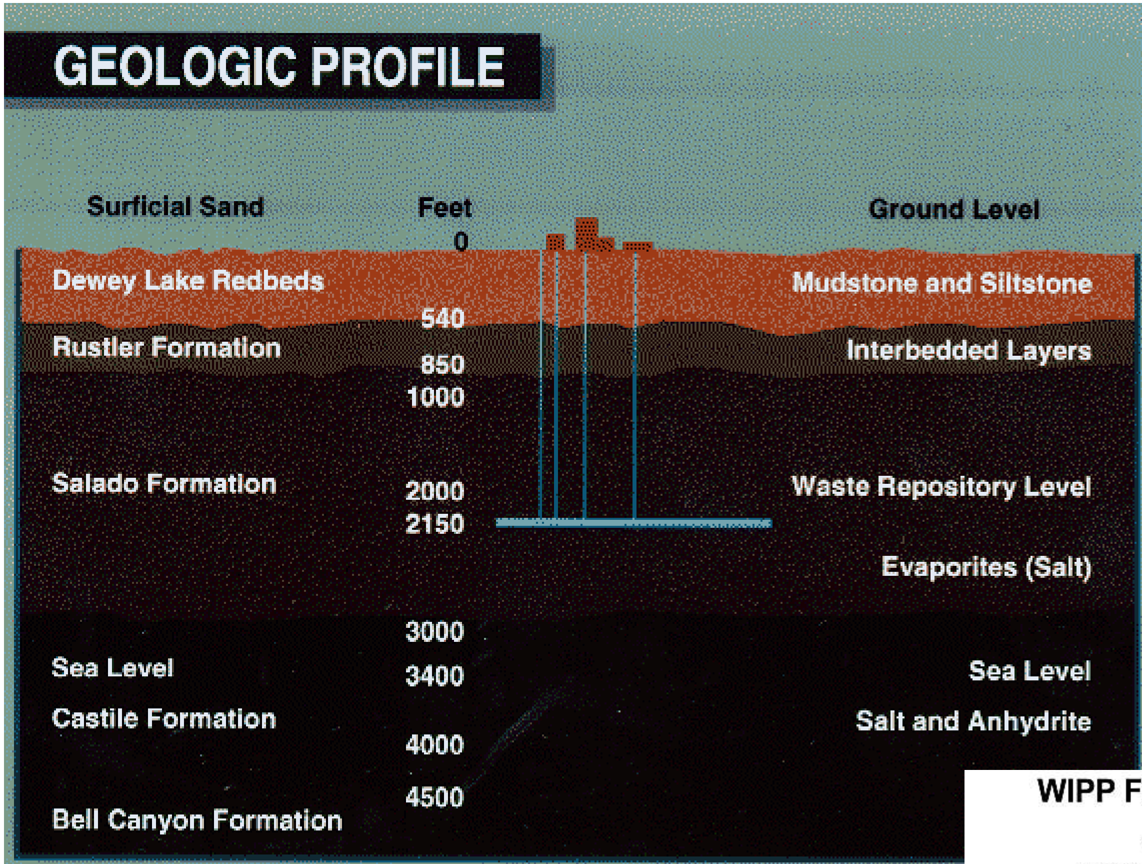




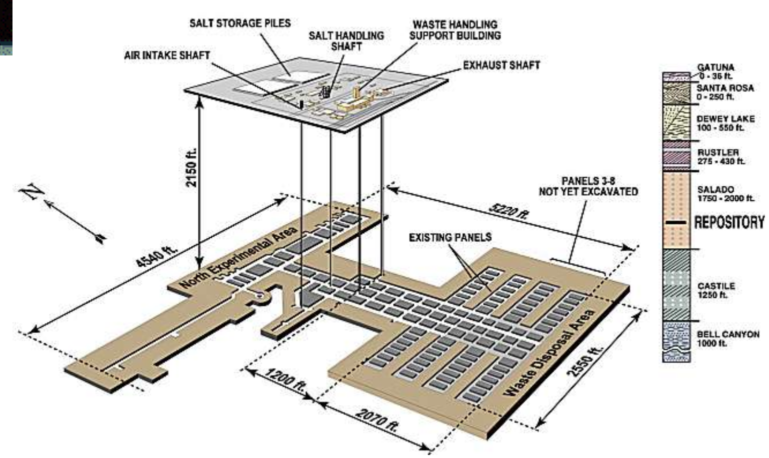
Waste Isolation Pilot Plant (WIPP)

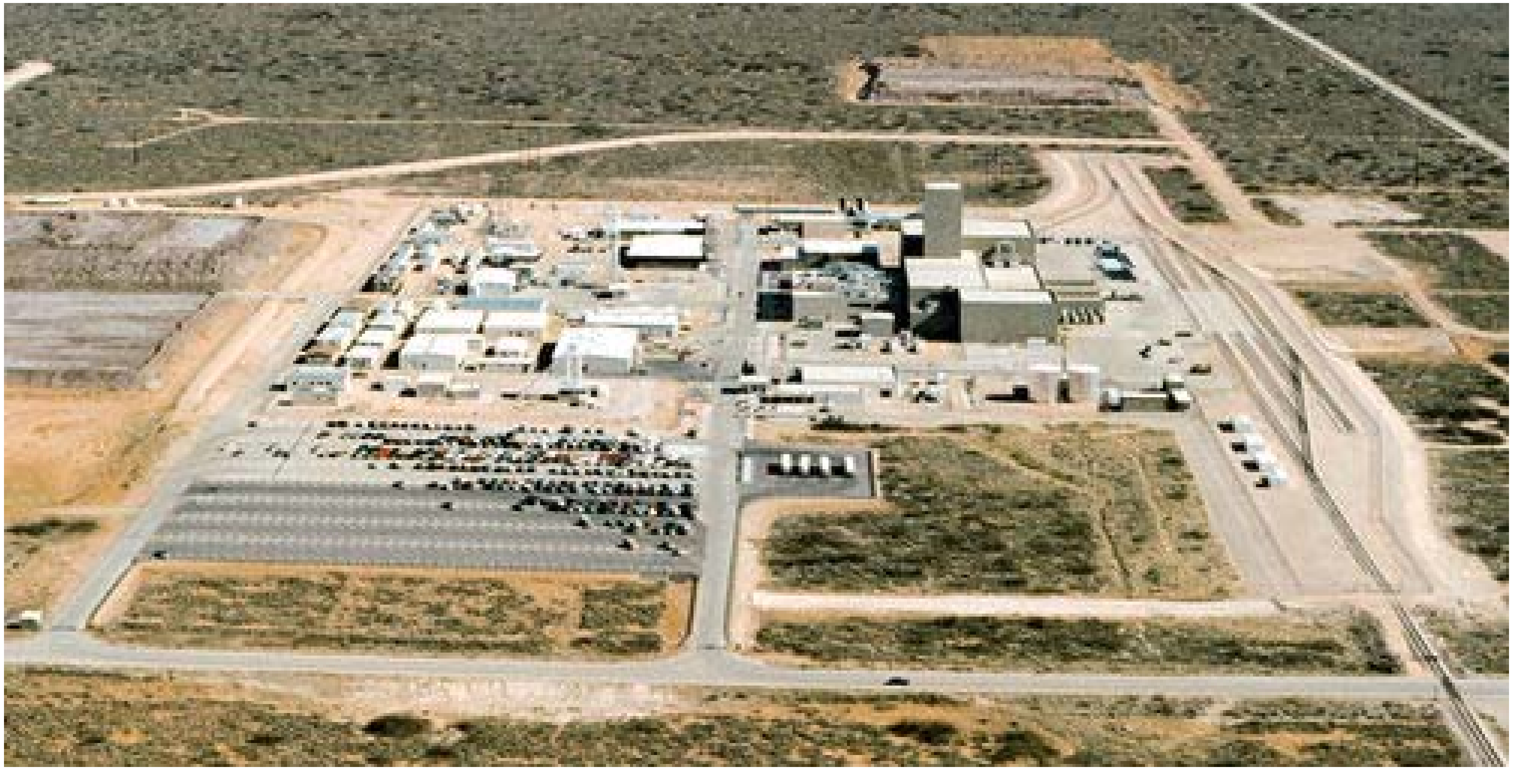
First US Geological Repository

Carlsbad, New Mexico



WIPP Facility and Stratigraphic Sequence





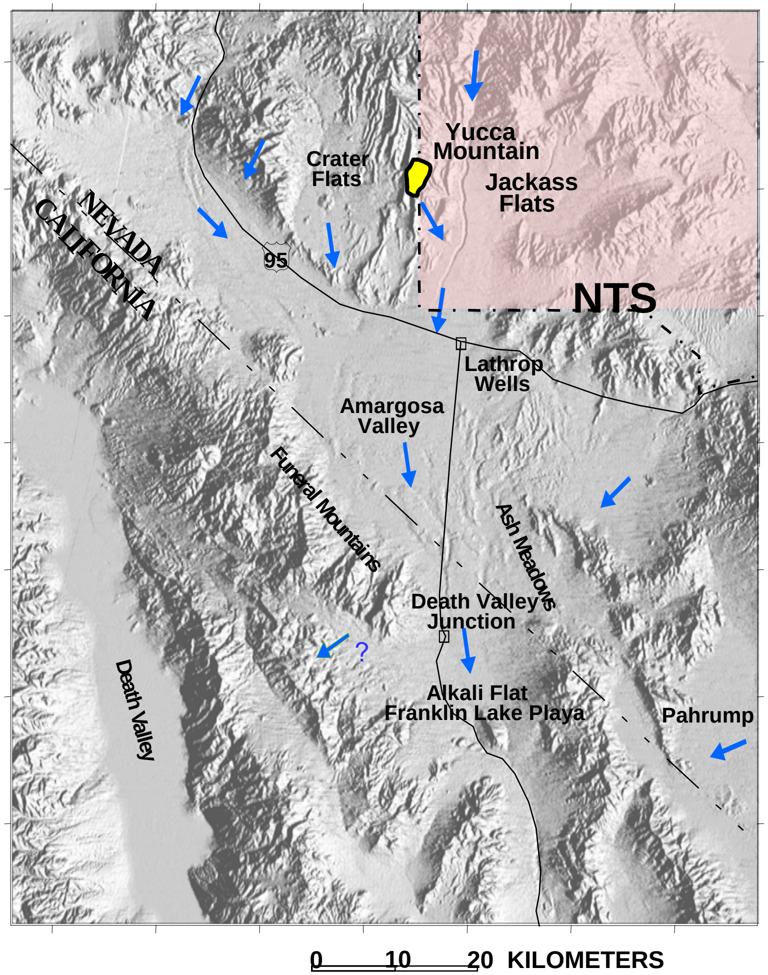

EMPTY




Gabon, Africa - Natural Nuclear Reactor

Viability Assessment: Total System Performance Assessment (Volume 3)

- **Water is the primary means by which radioactive elements could be transported from a repository**

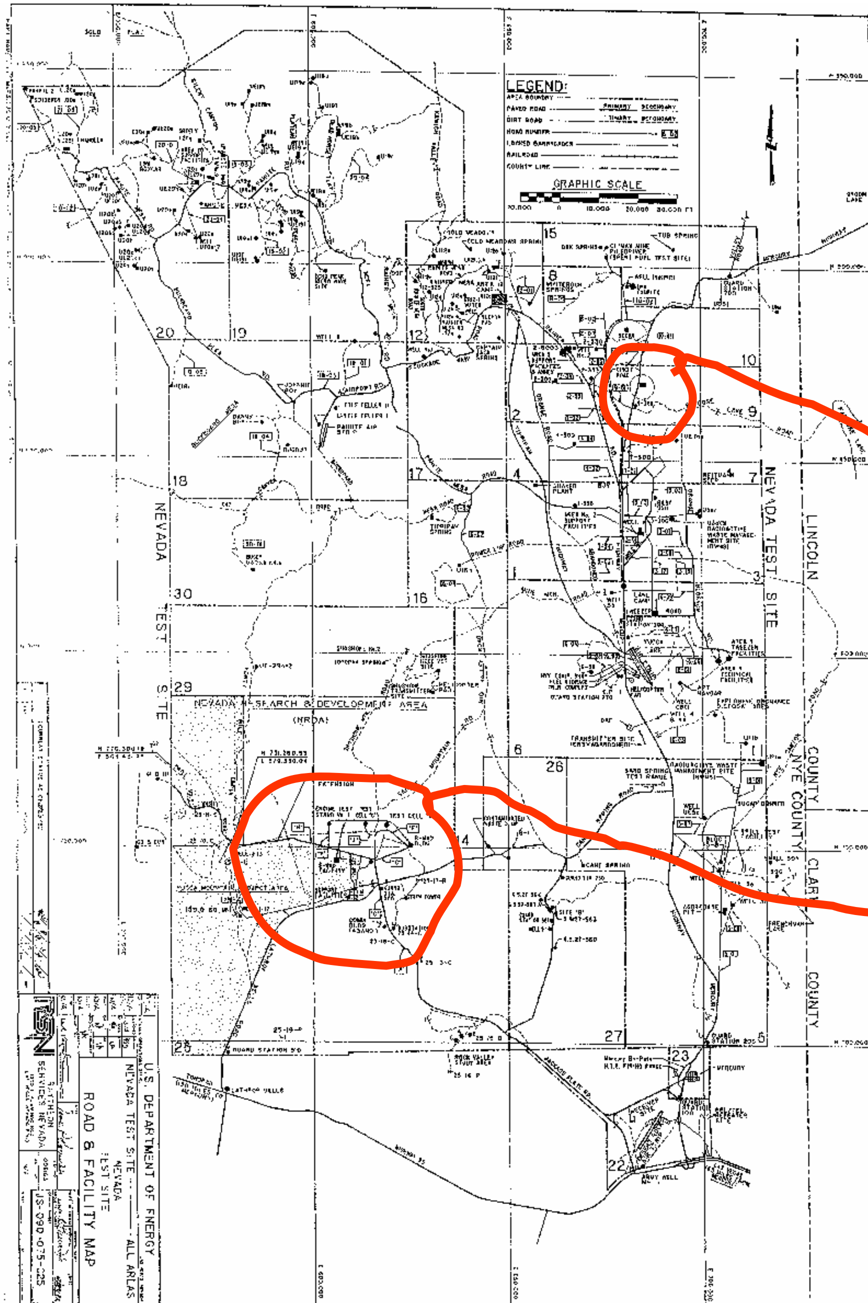


Groundwater Flow

- In general, flow is southerly
- Likely compliance point is at 20 km well (approximately at Nevada Test Site fence line or Lathrop Wells)
- Natural discharge of groundwater from beneath Yucca Mountain probably occurs at Franklin Lake Playa, although spring discharge in Death Valley is a possibility

Blue arrows indicate underground water flow

Nevada Test Site

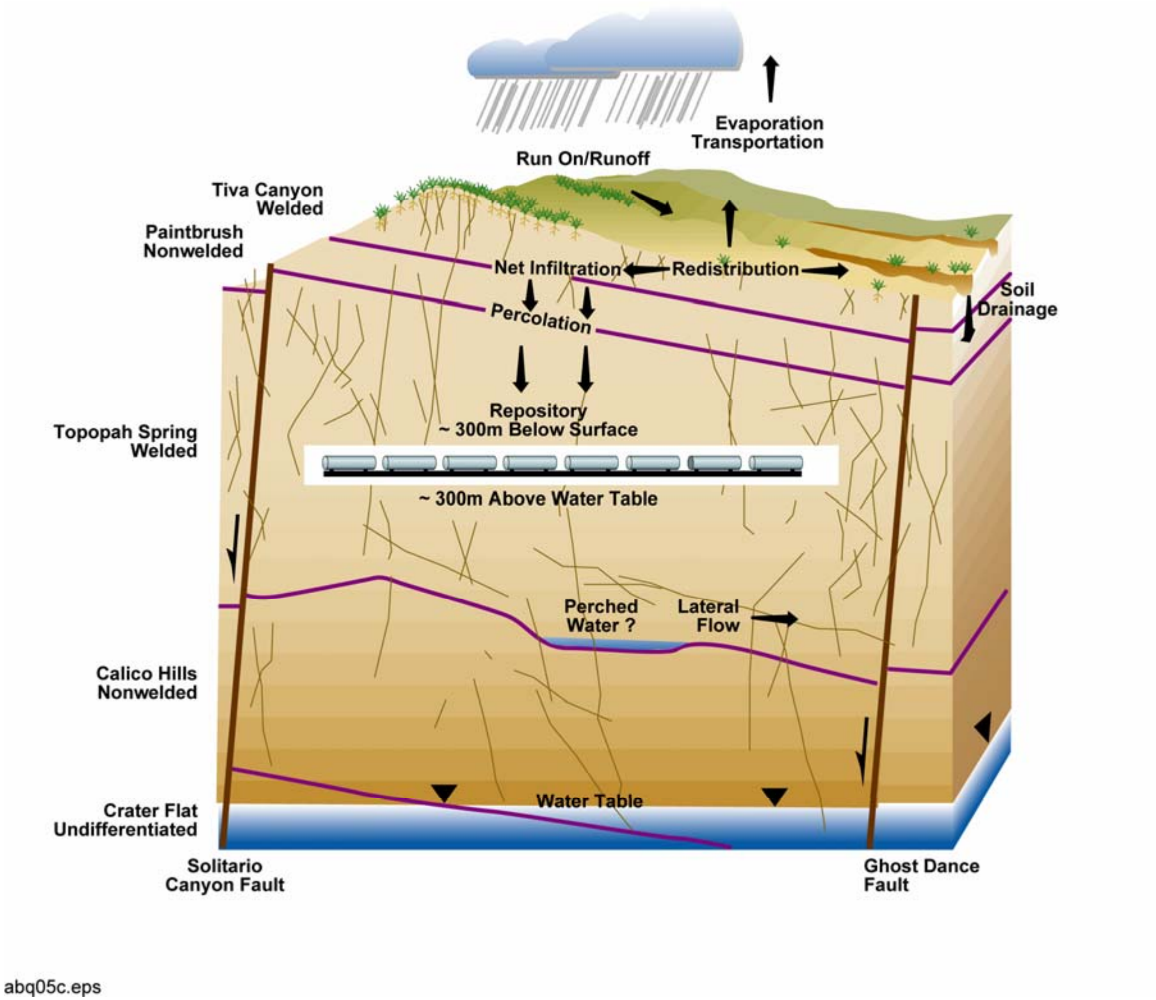


Underground Nuclear Explosion Locations

Yucca Mountain

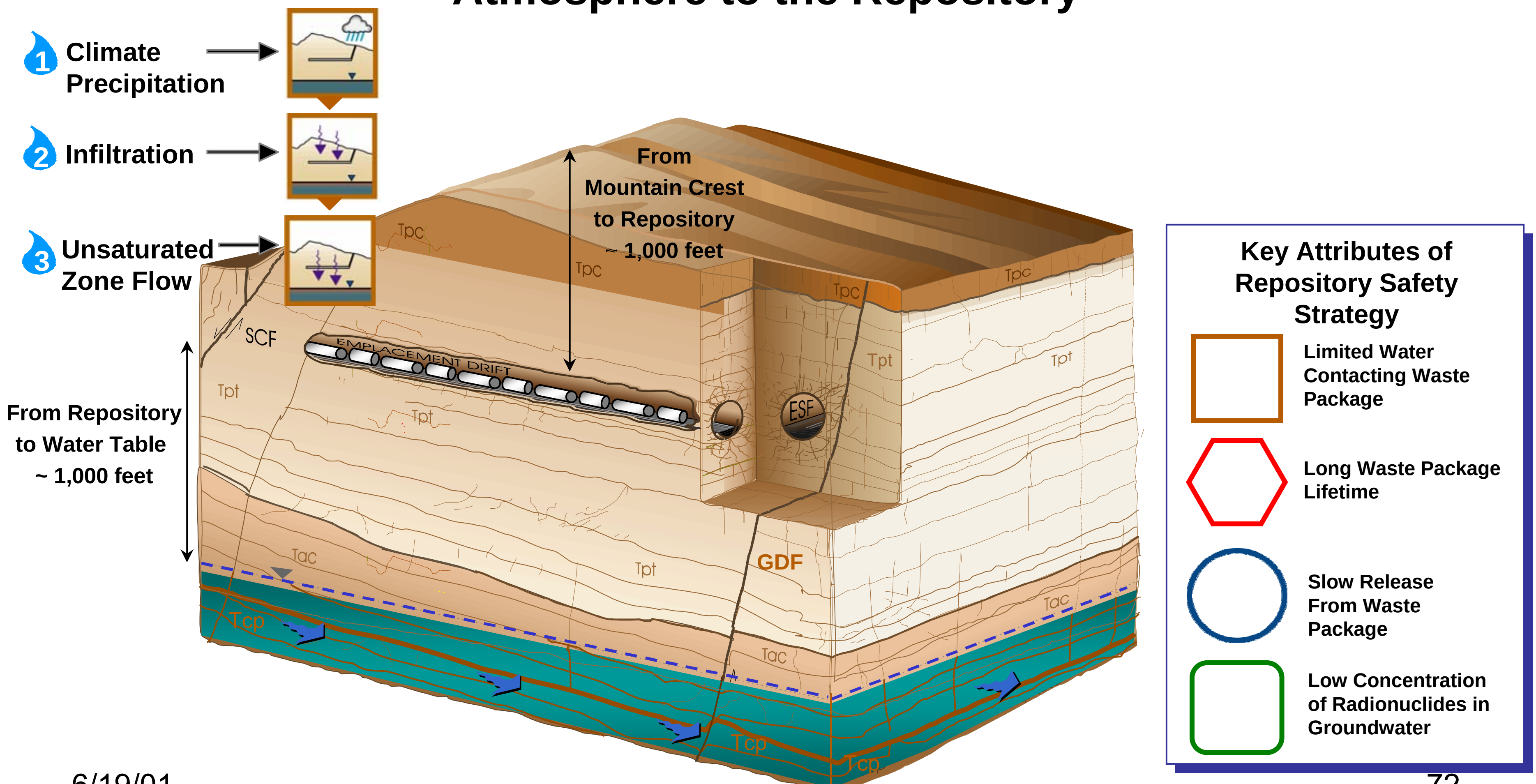
Viability Assessment: Total System Performance Assessment (Volume 3)

Water Movement Through the Geologic Formations



Viability Assessment: Total System Performance Assessment (Volume 3)

Modeling of Groundwater Flow Processes from the Atmosphere to the Repository



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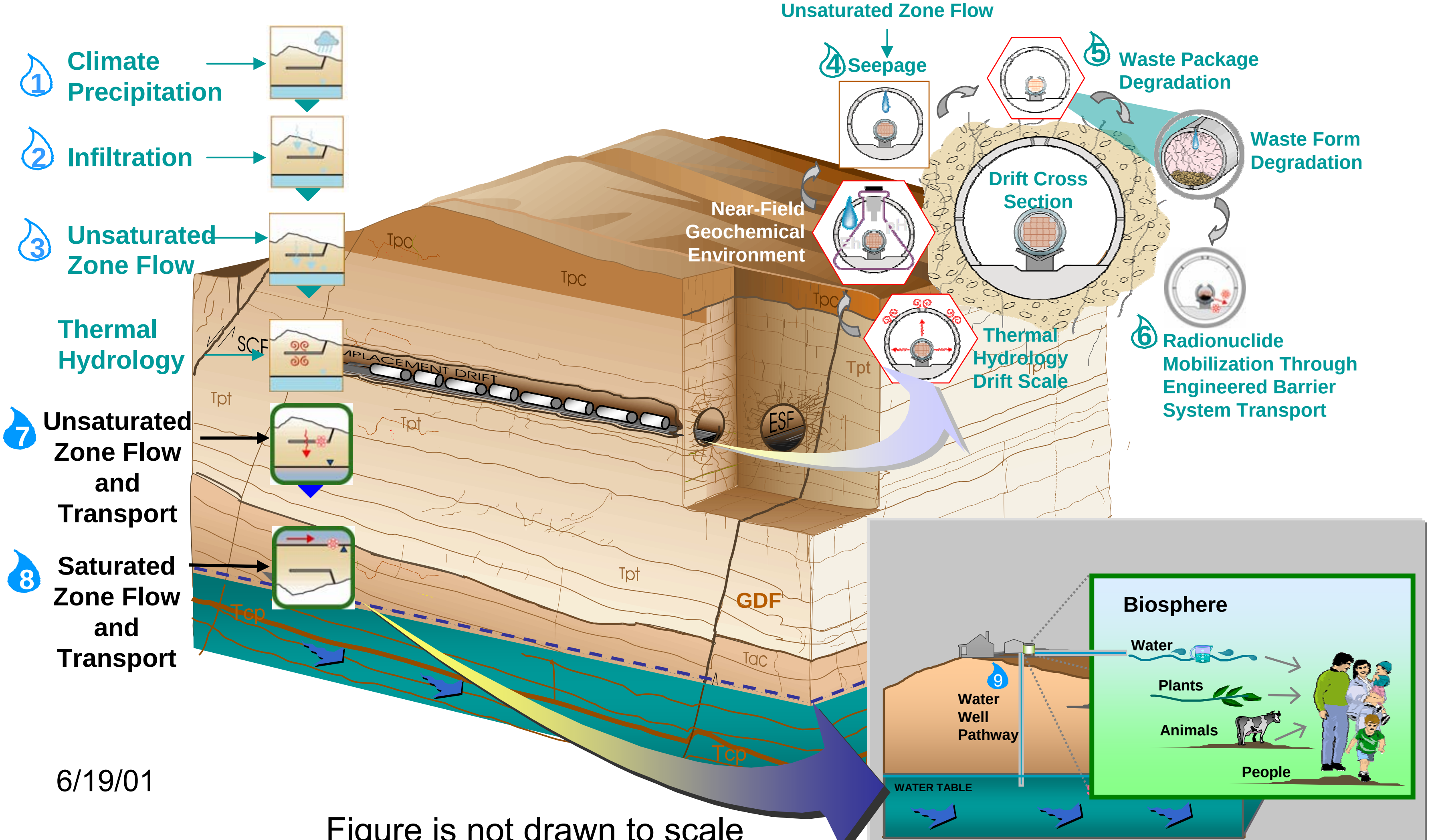
Viability Assessment:
Total System Performance Assessment (Volume 3)

Groundwater Flow Processes from the Repository Tunnels to the Accessible Environment



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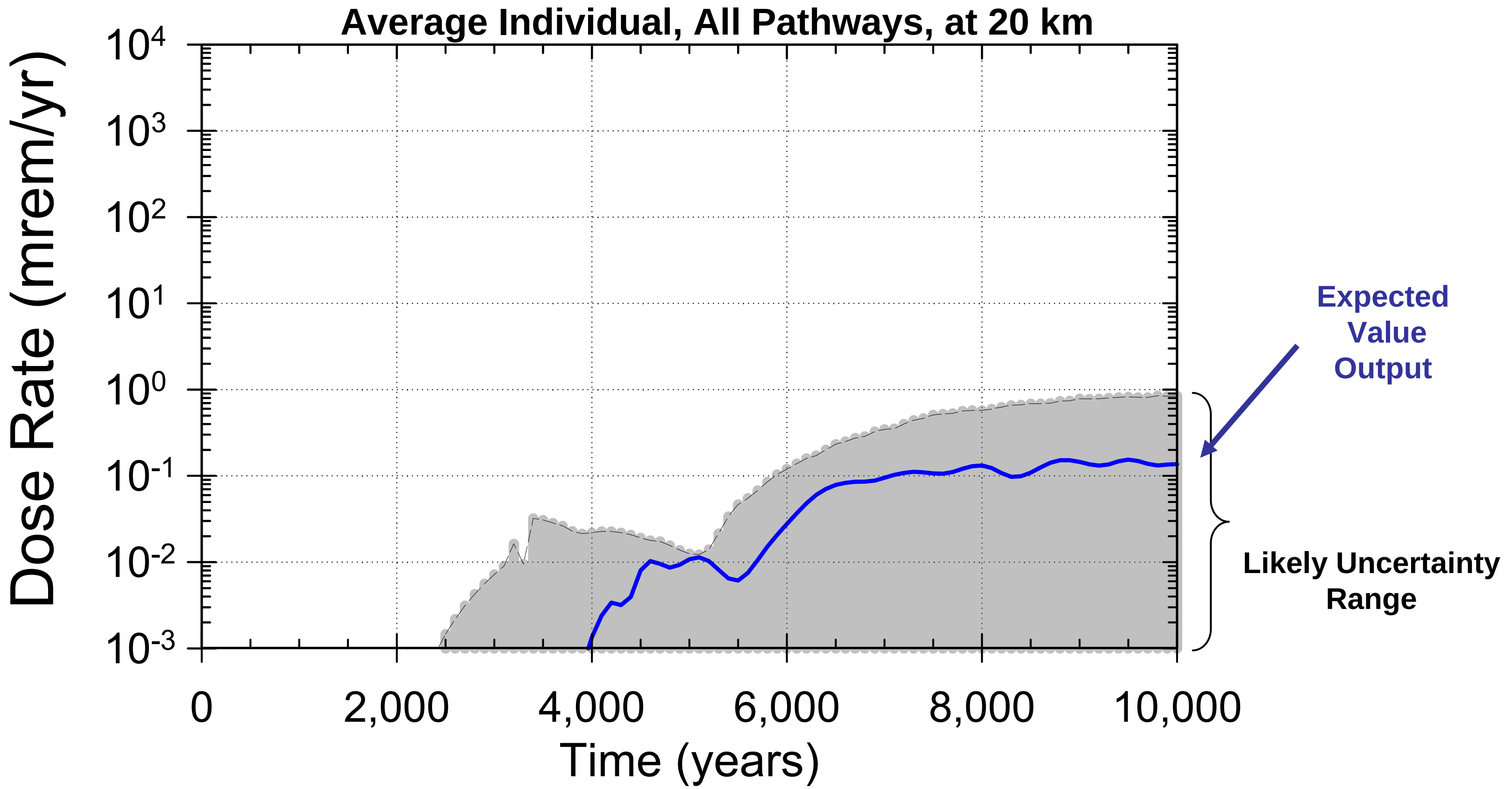
Total System Performance Assessment

<u>Results</u>

Expected 10,000-Year Dose-Rates

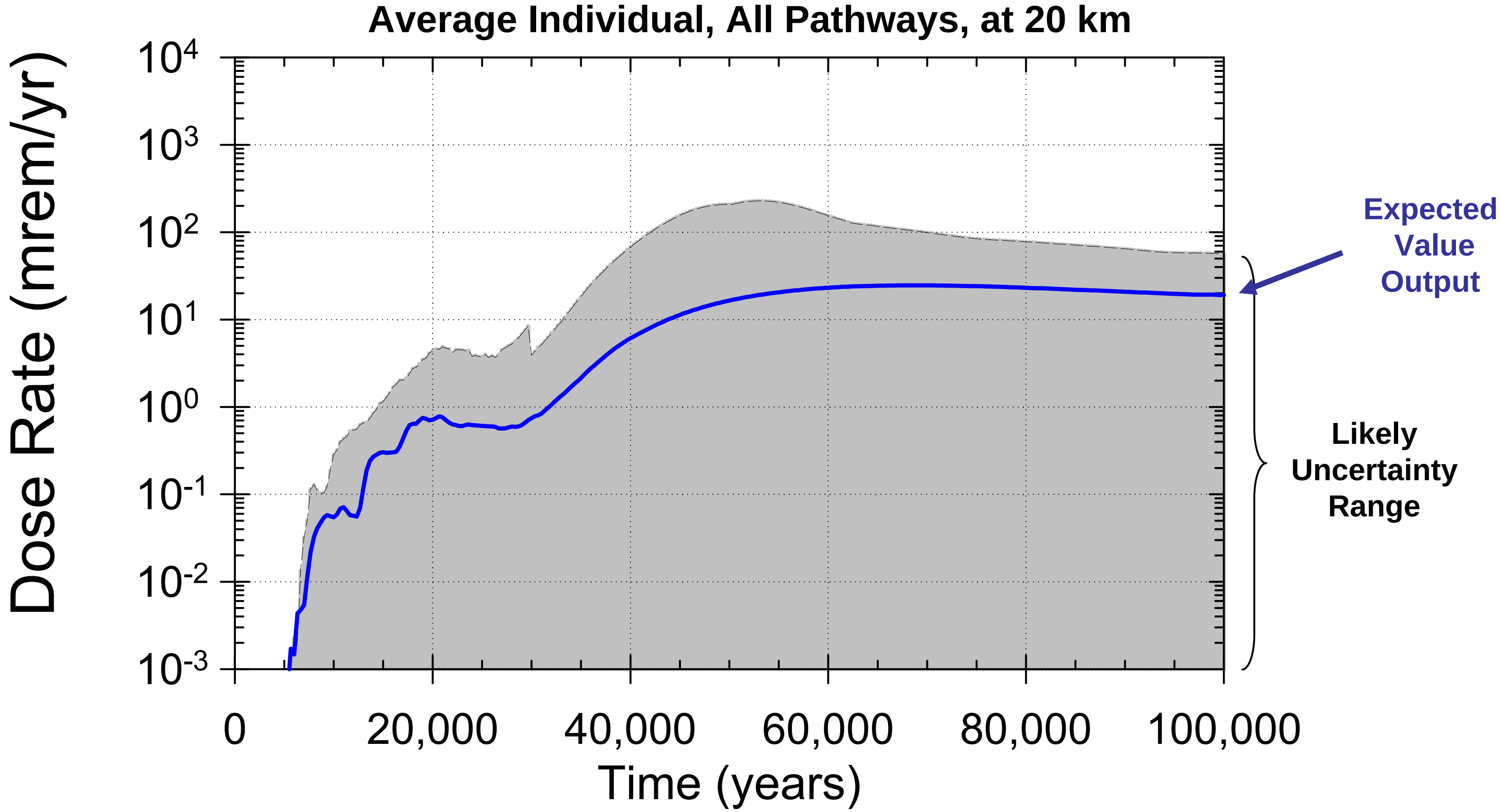


These analyses represent an all-pathways individual dose rate at 20 kilometers using ICRP-30 (International Commission on Radiological Protection). These results are model-specific and may be insufficient for future licensing proceedings.

Total System Performance Assessment

Results

Expected 100,000-Year Dose-Rates



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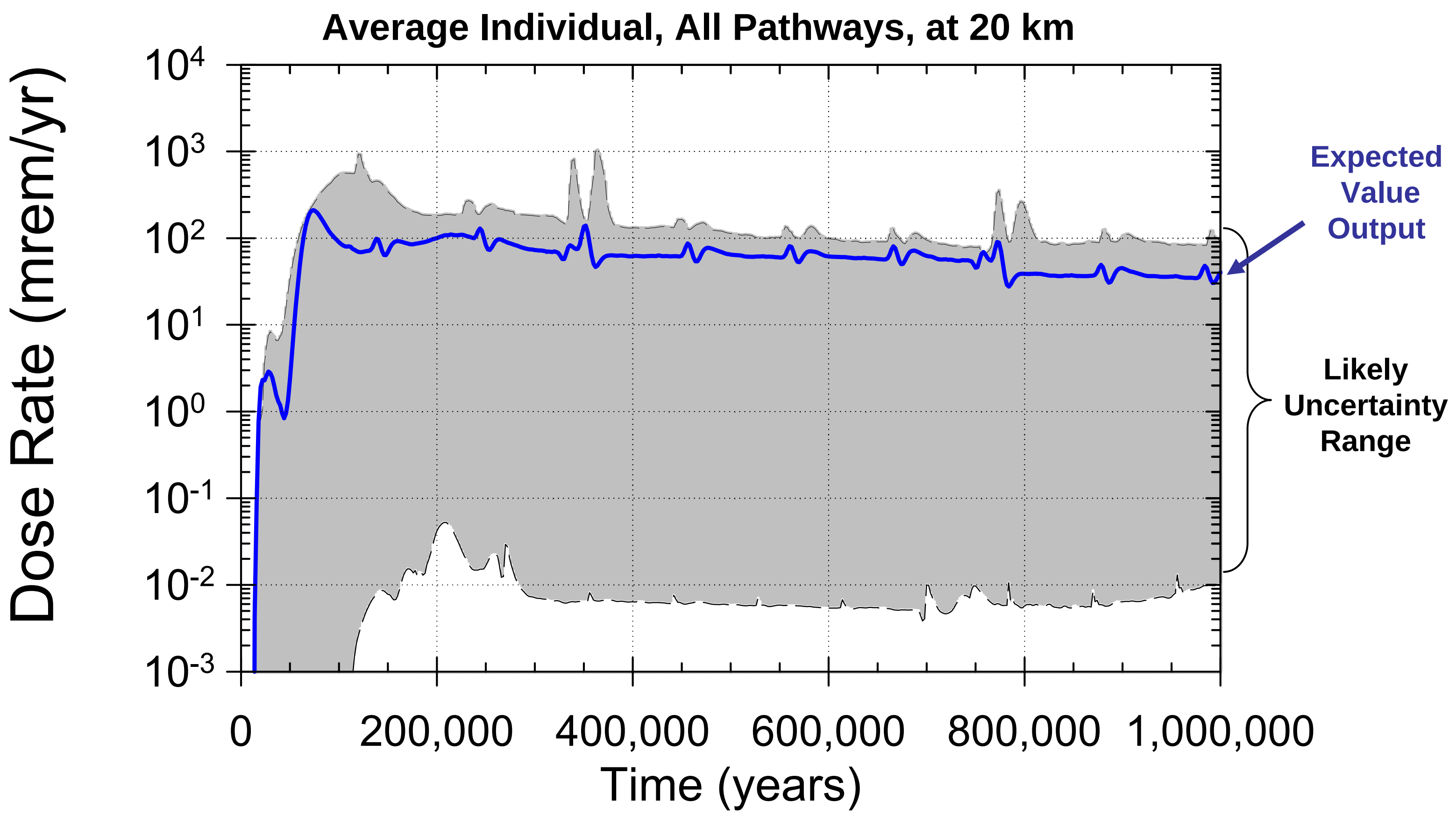
Total System Performance Assessment

Results

Expected 1,000,000-Year Dose-Rates



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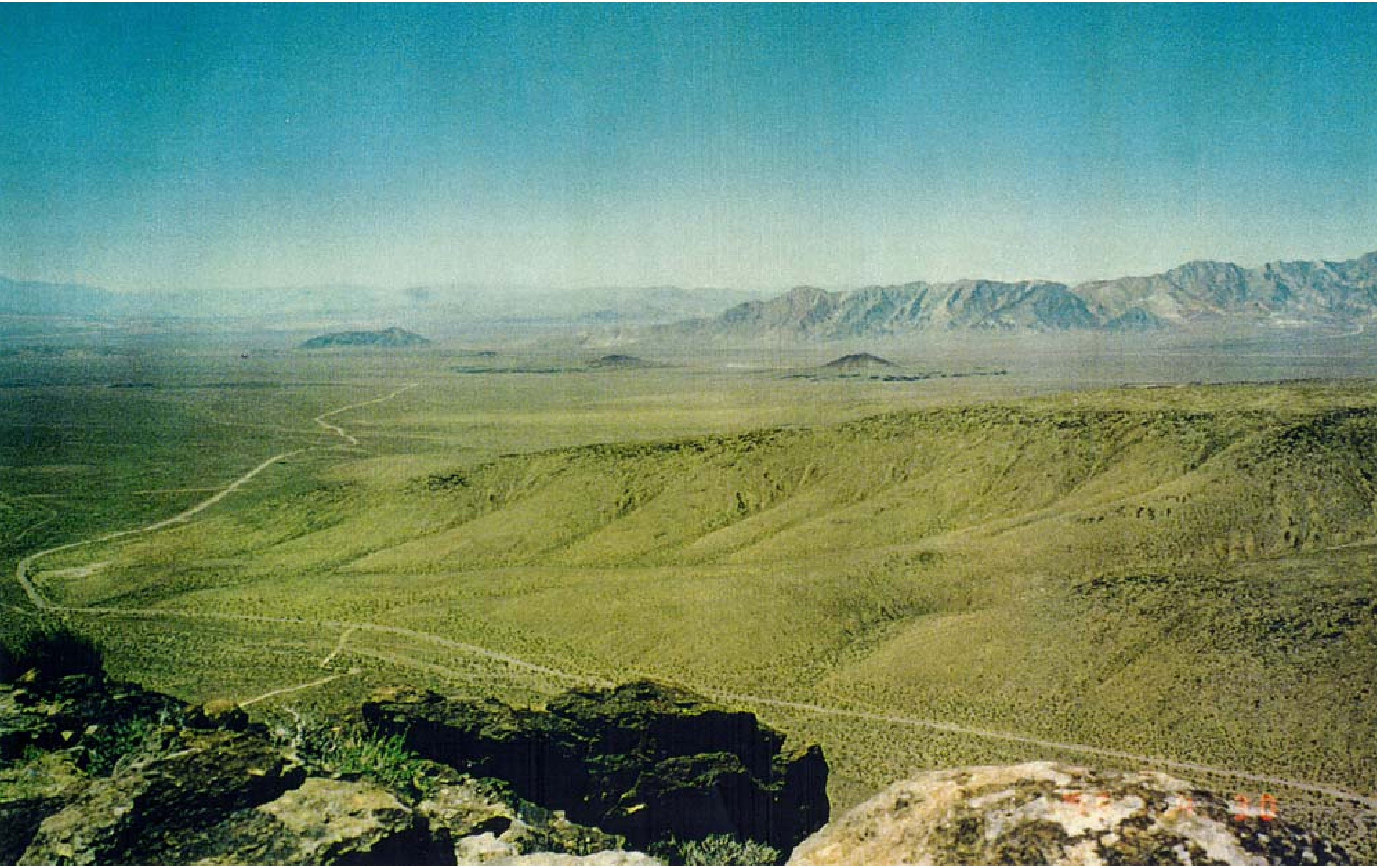
YUCCA MOUNTAIN IN THE BACKGROUND

PROPOSED STIE OF CENTRAL INTERIM STORAGE FACILITY

View from the Top of Yucca Mountain



TESTING OF SPENT FUEL TRANSPORT CASKS

Transportation containers for used nuclear fuel are designed to withstand accidents more serious than they will ever likely face without breaking open.

- **Before a container is licensed for use by the Nuclear Regulatory Commission, it must meet rigorous design requirements. The containers must be able to withstand being:**

1. Dropped 30 feet onto a flat, unyielding surface.
2. Dropped 40 inches onto a vertical steel bar 6 inches in diameter.

3. Engulfed in a 1,475 degree fire for 30 minutes.
4. Submerged under 3 feet of water for 8 hours.

- **Scientists at Sandia National Laboratory also tested the containers' integrity under scenarios that would exceed NRC requirements:**

The container was loaded on a truck and crashed at 80 miles per hour into a 700-ton concrete wall backed with 1,700 tons of dirt.

In a separate test, it was broadsided by a 120-ton locomotive traveling at 80 miles per hour.

- **In all of these tests, the transportation containers retained their integrity and would have kept the radioactive cargo locked safely inside.**

SFR

CLAB

Transportation system

Rock cavern in SFR

Storage pools in CLAB

Light at the End of the Tunnel

Solutions for US Energy Concerns

- Nuclear, Renewable Energy and Coal with CO_2 Sequestration can provide domestic sources for electricity without emissions.
- Efficiency improvements can only help reduce demand but not eliminate it
- Transportation energy source alternatives are needed:

  Electrical Batteries and hydrogen fuel cells are desirable but have many challenges
- Hydrogen is an energy carrier not an energy source

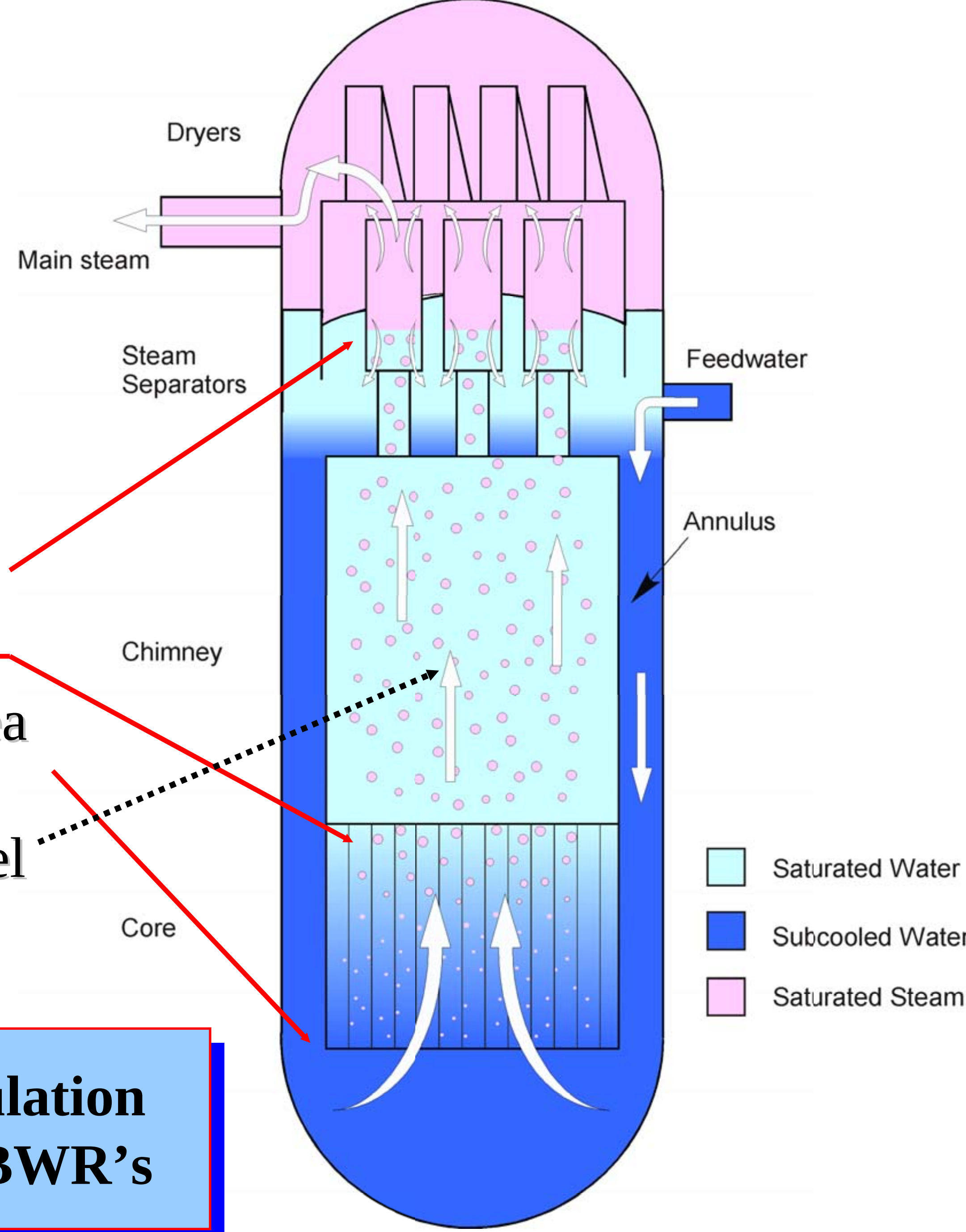
Resources

- www.iea.org
  - Tons of World energy data
- www.eia.doe.gov
  - Tons of U.S. energy data

ESBWR Design Features

- Natural circulation Boiling Water Reactor
- Passive Safety Systems
- Key Improvements:
  - Simplification
    - Reduction in systems and equipment
    - Reduction in operator challenges
    - Reduction in core damage frequency
    - Reduction in cost/MWe

- Reduced flow restrictions
    - improved separators
    - shorter core
    - increase downcomer area
- Higher driving head
    - chimney and taller vessel



Enhanced Natural Circulation Compared to Standard BWR's

Differences relative to ABWR

ABWR	ESBWR
Recirculation System + support systems	Eliminated (Natural Circulation)
HPCF (High Pressure Core Flooder) (2 each)	Combined all ECCS into one Gravity Driven Cooling System (4 divisions)
LPFL (Low Pressure Core Flooder) (3 each)	
RCIC (Isolation/Hi-Pressure small break makeup)	Replaced with IC heat exchangers (isolation) and CRD makeup (small break makeup)
Residual Heat Removal (3 each) (shutdown cooling & containment cooling)	Non-safety shutdown cooling, combined with cleanup system; Passive Containment Cooling
Standby Liquid Control System–2 pumps	Replaced SLCS pumps with accumulators
Reactor Building Service Water (Safety Grade) And Plant Service Water (Safety Grade)	Made non-safety grade – optimized for Outage duration
Safety Grade Diesel Generators (3 each)	Eliminated – only 2 non-safety grade diesels

2 Major Differences – Natural Circulation and Passive Safety

Why Was AP1000 Developed?

- **Existing designs with incremental improvements could not meet the deregulated electricity generation cost target**
- **Westinghouse Passive Plant Technology was mature and licensed in US**
- **Large investment in Passive Plant Technology development could be leveraged to provide a cost competitive design in a relatively short time**

Passive Safety Advantages

- **No reliance on AC power**
- **Automatic response to accident condition assures safety**
- **Long term plant safety assured without active components (natural forces only)**
- **Containment reliability greatly increased by passive cooling**
- **In severe accidents, reactor vessel cooling keeps core debris in vessel**
- **Large margin to safety limits**
- **Defense in depth - active non-safety systems provide additional first line of defense**

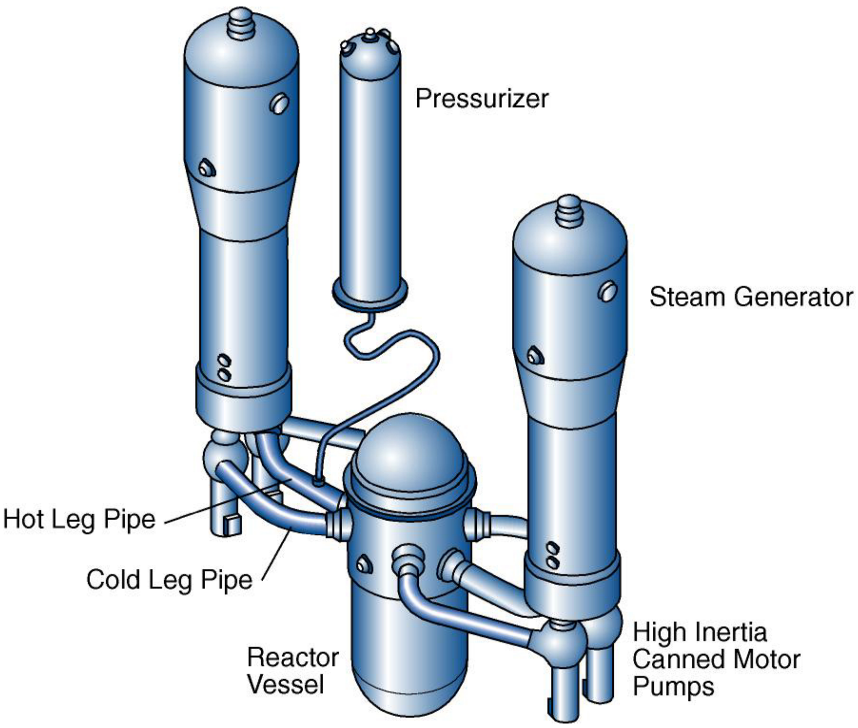
AP1000 Design Objectives

- **Increase Plant Power Rating to Reduce Cost**
  - Obtain capital cost to compete in US deregulated market
- **Retain AP600 Design Basis and Detail**
  - Increase capability/capacity within “space constraints” of AP600
  - Retain credibility of “proven components”
  - Retain basis and pedigree for cost estimate, schedule, modular scheme
- **Retain AP600 Licensing Basis**
  - Meet regulatory requirements for Advanced Passive Plants
  - Demonstrate AP600 Test Program and Safety Codes are applicable to AP1000

Build on AP600 Investment

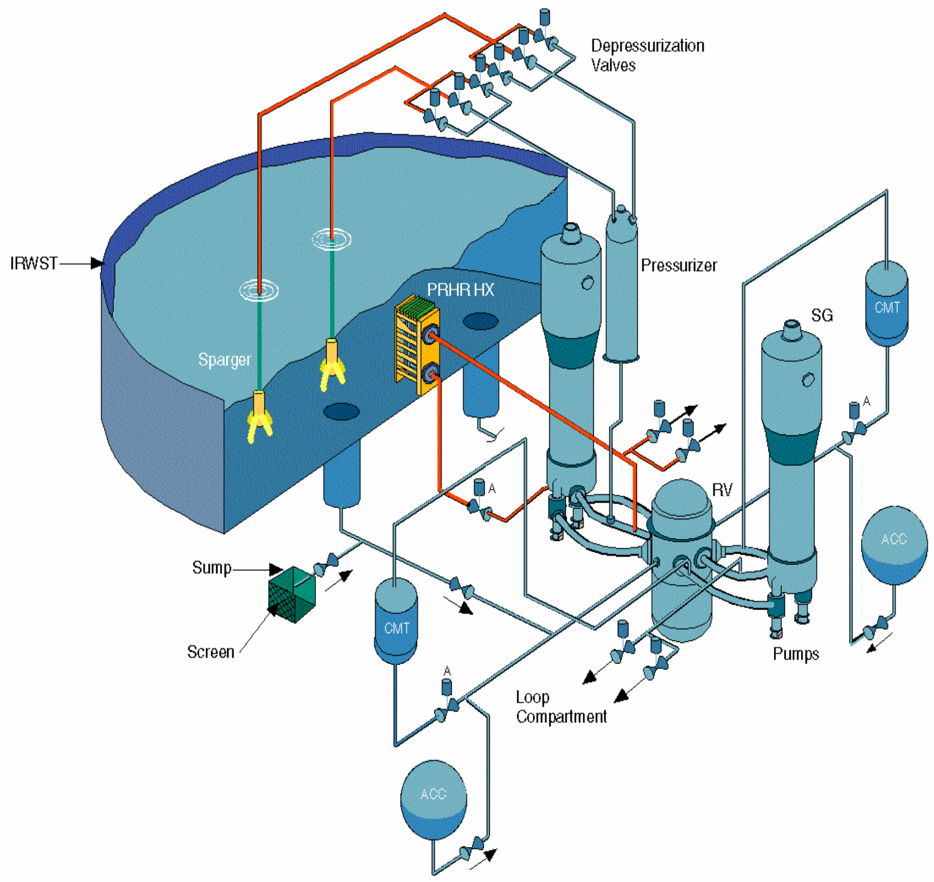
Reactor Coolant System

- Canned motor pumps mounted in steam generator lower vessel head
- Elimination of RCS loop seal
- Large pressurizer
- Top-mounted, fixed in-core detectors
- All-welded core shroud
- Ring-forged reactor vessel

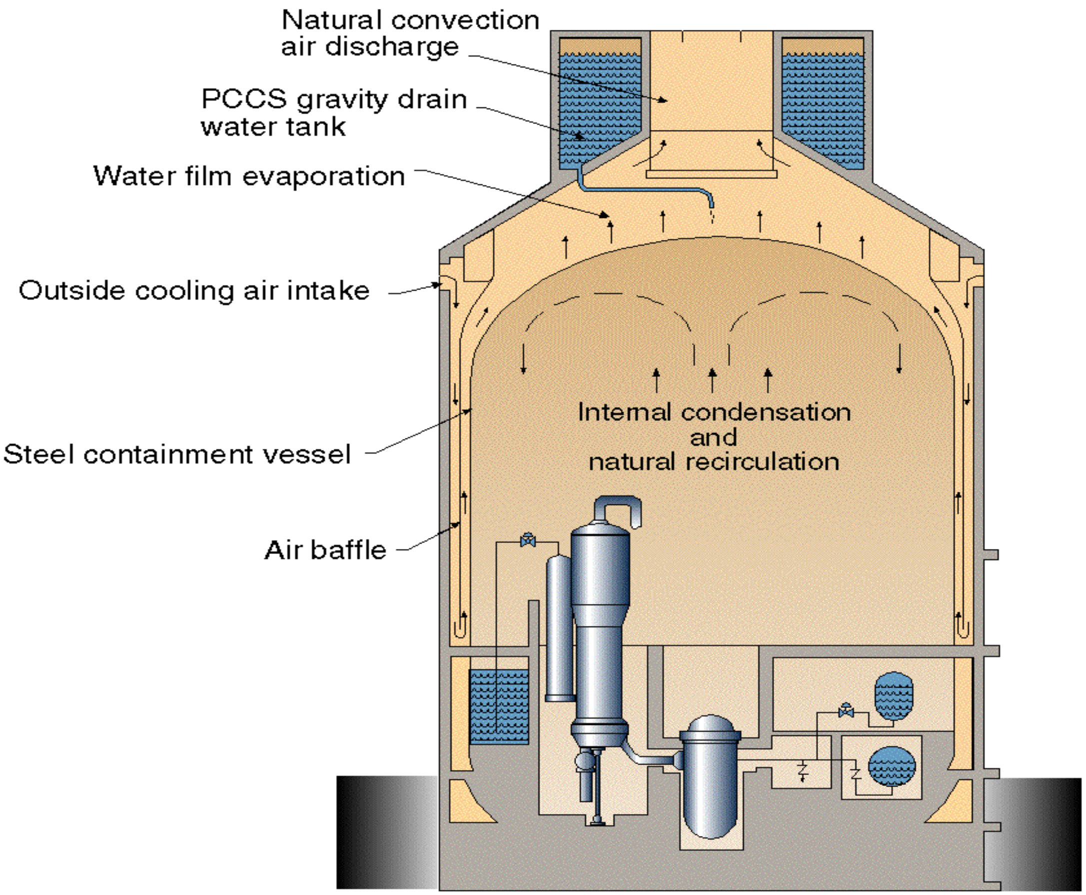


Passive Core Cooling System

- **AP1000 has no reliance on AC power**
  - **Passive Decay Heat Removal**
  - **Passive Safety Injection**
  - **Passive Containment Cooling**
- **Long term safe shutdown state > 72 hours without operator action**

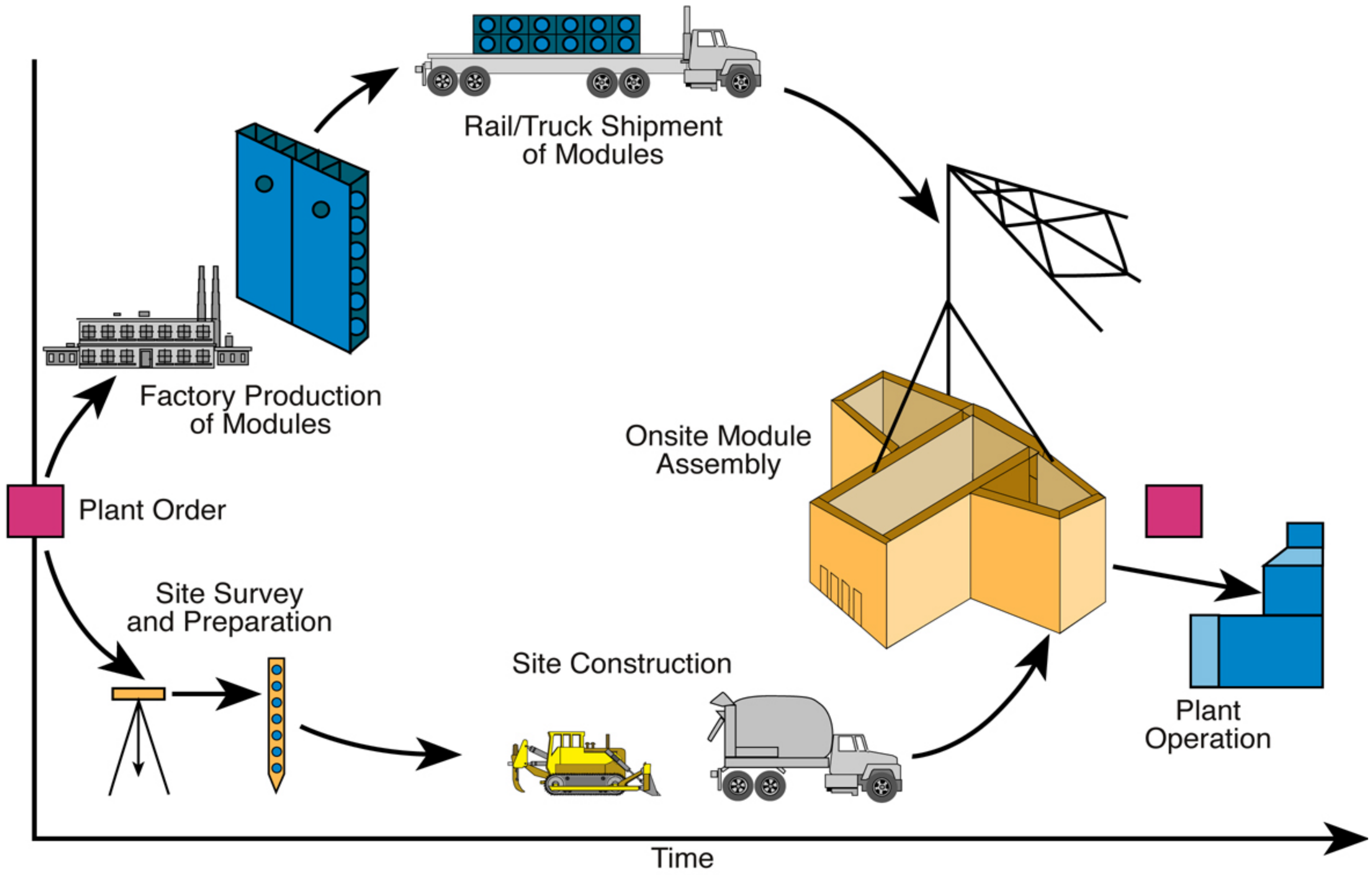


Passive Containment Cooling



Advanced Control Room

Parallel Tasks Using Modularization Shorten Construction Schedule



European Pressurized Water Reactor

EPR Safety System